ELECTRIFICATION OF CHICAGO SUBURBAN SERVICE OF C. B. & Q. R. R.

BY

P. G. DOWNTON

ARMOUR INSTITUTE OF TECHNOLOGY

1914

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THE ELECTRIFICATION PROJECT
# of the
CHICAGO SUBURBAN SERVICE
# of the
CHICAGO, BURLINGTON & QUINCY R.R.

A THESIS
presented by
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PREFACE

PREFACE

The question of the electrification of steam railroads is one of vital importance at the present time. The proposition of the electrification of the suburban service of the Chicago, Burlington, and Quincy R.R. was covered in a thesis presented in 1909 of which the writer was part author. This thesis is taken as the basis for the present thesis.

The thesis above referred to was largely a motor characteristic study. The question of system was briefly treated at that time but it was not the intention of the writers at that time to go into that question very thoroughly as the time available was limited and it was thought more desirable to spend the time otherwise.

At that time it was decided that the best available system was an alternating cuurent one and a voltage of II,000 single phase was selected. Almost the entire thesis was then devoted to the problem of electrification on that basis.

It is the present intention of the writer to pass over the arguments for and against different systems and to study the proposition from the point of view of operating from a third rail at 600 volts direct current. It is also assumed that the system will be operated by purchased power and considerable space will be devoted to a power

study. It is assumed that this power can be pur- at about 33,000 volts three phase at some convenient point along the line, probably at Chicago or at Riverside.

The part of the system to be electrified is the same as in the previous consideration. This canstitutes the suburban service between Chicago and Aurora. There are four tracks part of the way but where this is the case only three of them are at the present time used for passenger service so that it will be assumed that the fourth track will not be electrified. This means that three tracks will be electrified from Chicago to Downers Grove and two tracks from there to Aurora. This is shown in Fig. 2 and the profile of the road in Fig.I.

For the sake of clearness, this thesis is divided into three parts. The first part consists of the general outline and details, the second consists of the calculations, and the third consists of the curves. The first part naturally includes much of the second part but it was thought that the results would be more clearly shown if outlined as above.

SCHEDULE & EQUIPMENT

SCHEDULE and EQUIPMENT

The details of the above are largely assumptions made on the basis of the work done on these questions in the previous thesis. The schedule was originally made up from a study of the suburban schedule in effect at the time. The schedule has been assumed without change and is shown graphically in Figures 5 and 6.

The schedule as shown gives hourly service between Chicago and Aurora with stops at Hinsdale and all points between Downers Grove and Aurora, hourly service between Chicago and Downers Grove with stops at Berwyn and all points between Riverside and Downers Grove and hourly service between Chicago and Riverside with all stops between these two points. In addition to this service, a one car train is to be operated between Riverside and Downers Grove so as to fit in with the express service. The service at the busy times is figured so as to accomodate about the same number of passengers that use the service now.

The next assumption was with regard to the car equipment. The car selected before had a seating capacity of about sixty and weighed 52.5 tons. Allowing for the excess weight of a car used on alternating current work and taking into consideration the standard used on roads of this kind in

similar work, a car weight of 45 tons was assumed. The seating capacity was assumed at sixty and the average load was assumed to be forty persons weighing about 150# each. This gives a total weight of 48 tons.

It was also assumed that a suitable motor could be obtained so as to give a speed time curve approximately the same as the one obtained for the A.C. operation and shown in Fig. 3. This would then give the schedule speed used in the timetable used.

The schedule speed necessary was 33 miles per hour and the maximum speed 60 miles per hour.

POWER CONSUMPTION

POWER CONSUMPTION

The study made of power consumption for the A.C. proposition showed a power input at the motor of 3.4 K.W. hrs. or with the weight used of 52.5 tons, this meant an input to the motors of 64.7 watt hrs. per ton mile. This figure is somewhat lower than the figures usually assumed and it is very doubtful if it could be obtained as an average figure. To be conservative, I have assumed a watt hour per ton mile input of 75 watt hours per ton mile which means an output of 64 watt hours per ton mile with a motor efficiency of 85%.

With this input, the watt hours per car mile will be 3600. With a schedule speed of 33 miles per hour, this will mean an average input at the car of 118.8 K.W.

It is customary with installations of this kind to assume an average voltage drop of 10% as a working basis. This would give an average voltage at the car of 540. At this voltage, the average current input per car is 220 amperes.

The starting current usually figures between two and three times the normal running current. In this case I have assumed 2.5 times to be a fair figure. This checks quite closely with the ration used in the previous motor study.

LOAD DISTRIBUTION

LOAD DISTRIBUTION

The load per mile varies with the density of the traffic. The zone to be electrified is in three distinct divisions. These are from Chicago to Riverside, from Riverside to Downers Grove and from Downers Grove to Aurora. These divisions are clearly defined as all of the trains are operated to one of these terminals.

Treating these three divisions in their order, we have in the first division 9 - 5 car trains, I6 - 4 car trains, 8I - 3 car trains and I7 - 2 car trains. At 3.6 K.W. hours per car mile, we have I389.6 K.W. hours per mile per day or I5424.56 K.W. hours per day for the division of II.I miles.

For the second division, we have 9 - 5 car trains, I0- 4 car trains, 48 - 3 car trains, 24 - 2 car trains and I7 - I car trains. This means 972 K.W. hours per mile per day or 98I9.2 K.W. hours per day for the division of I0.I miles.

For the third division, we have 9 - 5 car trains, 5 - 4 car trains, 32 - 3 car trains and II - 2 car trains. This gives a total of 658.8 K.W. hours per mile per day or I0672.36 K.W. hours per day for the division of I6.2 miles.

The total of these three gives the total

load on the system with the exception of transmission losses. This means a total motor input of 359I6.I2 K.W. hours per day.

SUBSTATION LOCATION

SUBSTATION LOCATION

It is desirable to have the substations so located that the whole system is fed without any excessive copper and also that the substations be near enough the points of heavy momentary load to carry it without excessive voltage drops. The points that will probably have the heaviest starting loads will be Chicago, Western Ave., Riverside, and Downers Grove. It is also found necessary ordinarily to have substations on a 600 volt system located not more than ten miles apart.

Assuming three substations, the average daily load would be approximately 12000 K.W. hours. This number would make the average spacing more than ten miles and would put the substations too far from the ends of the system, particularly the Chicago end.

If four substations are used, the average daily load would be approximately 9000 K.W. hours. This number was found to work out very nicely and on this basis, the substations were located as follows:-

Substation A	Western Ave.(1.4 mi.)
Substation B	Riverside9(11.1 mi.)
Substation C	Downers Grove(21.2mi)
Substation D	Eola (33.5 mi.)

This arrangement provides a substation at

each of the points of very heavy load except Chicago and provides a substation only I.4 miles from there. There is also a substation 3.9 miles from the other end of the system and the spacing adheres quite closely to the standard spacing of ten miles.

The approximate division of load with this arrangement figuring on the basis of the motor input totals arrived at above, would be

Substation A	8765	K.W. hours per day
Substation B	II648	K.W. hours per day
Substation C	8950	K.W. hours per day
Substation D	66II	K.W. hours per day

Considering the density of the load, this makes a very satisfactory load distribution.

SUBSTATION LOAD.

SUBSTATION LOAD

The equipment as to rails and feeders will not change between substations so that the division of load will be inversely proportional to the distance of the substations from the load.

The schedule was analyzed and the results noted in Table I. This table shows the distance of each train from Chicago every fifteen mintues and shows the number of cars per train. Only trains either running or starting are shown. Where the schedule of a train ends at the point at which the readings are taken, no notation is made in the table.

The current was figured from the number of cars and the division of the load between the substations figured. Table 2 shows the current supplied by each substation evry fifteen minutes. The total current shown is the total current output from the substations and really means very little except for checking.

The substation efficiency was figured at 90%, this representing 93% rotary converter efficiency and 97% transformer efficiency.These figures are high if anything and will make the conclusions of the report more conservative.

The current firgures were reduced to K.W. output figures and by taking into consideration

the substation efficiency, the figures were reduced to substation input.

The transmission losses on a propostion of this kind are usually about I0% of the load. On this basis the total load was figured and is shown in Table 7.

Figures 7, 8, 9, I0, and II show the substation loads and the total load. In making these curves, it was assumed that the load values obtained from the figured above referred to are the correct values for the fifteen minutes centering on the time at which the readings are taken For reasons which will be explained later, the average load has been figured for each hour both for the individual substations and the total load.

ANALYSIS of LOAD & POWER COST

ANALYSIS of LOAD and POWER COST

As stated in the preface, this study is intended to be largely a power study made on the basis of purchased power. It is assumed that power can be purchased at Chicago or at Riverside For this analysis, the basis of charge is assumed to be the same as that in the contract made between the Chicago City Railway Company and the Commonwealth Edison Company. This is probably the best known contract of this kind. All of the details of this have been published in the technical periodicals.

The cost of power in this contract is based on two things. The first charge is the service or maximum demand charge. This is $15,00 per K.W. per year. The sedond charge is for the power consumed and is at the rate of $.004 per K.W. hour The maximum demand is an average figure. There is a natural morning peak and another in the evening. The maximum hourly reading for the morning peak and evening peak is taken for any three consecutive days and the average of these six readings is taken as the maximum demand for the year. The hourly readings are taken on the even hour and are taken automatically by a recording meter in the feeder circuit at the power plant from which the power is delivered. I have assumed these

conditions as applying exactly in this case. For the purpose of figuring power costs, I have assumed that the load is as shown in the curves for 300 days per year and that for the other 65 days it is one half of this. This latter firgure covers Sundays and holidays.

On the above basis, the cost of power was figured for various load factors. The load factor is assumed to be the ratio of the average load to the maximum hour as determined for the service charge. In this case, this is taken to be the average of the maximum morning hour and the maximum evening hour. It will be seen from the curve that the mimimum cost of power with 100% load factor is$.00587 per K.W. hour and the maximum cost at 1% load factor is $.192. It will be seen from these figures that there is a wide range in the cost of power depending entirely on the power factor. It is probably not quite accurate to figure that the same rates would apply over such a wide range of power factors it is accurate within the range to be considered.

An analysis of table 7 shows a maximum load of 4766 K.W. in the morning and 4477 K.W. in the evening. An average of these two gives a value of 4621.5 K.W. as the load which determines the service charge. This table also gives a total daily load of 48,140 K.W. per day. Assuming this load for 300 days and half of this load for the other

65 days, the total load per year is 16,006,550 K.W. hours. The cost of this at the power charge is $64,026.20. The service charge is $69,322.50. This makes a total power cost per year of $133,348.70 or a cost per K.W. hour of approximately $.00833. It will easily be seen that this cost is considably above the lowest possible cost which is as stated above, $.00587. It is, of course, impossible under ordinary circumstances to approach very close to this ideal price for power but it is perfectly possible to reduce the cost considerably. Ways of doing this will be discussed in detail in the following section.

WAYS OF REDUCING POWER COST.

WAYS OF REDUCING POWER COST.

It will be seen from a study of the preceding figures that the high cost of power is due primarily to the comparatively high maximum demand so that the only way this cost can be reduced is by reducing the peak. There are two ways in which this peak can be reduced. The first one that presents itself is that of holding an auxiliary power plant in readiness to carry part of the peak load. Probably the only practical power plant for a proposition of this kind would be a steam plant. If a steam plant were used, it is probable that the cost of keeping the boilers banked in addition to the overhead and labor charges would make the cost of operation greater than the saving effected. As a matter of fact, the surface lines in Chicago found that it would not pay to continue the operation of power plants already installed. In view of this fact, I do not believe that this means is worthy of serious consideration.

The other scheme that comes up for consideration is that of using a storage battery to discharge on the peaks and to charge at times of low load. This scheme has been tried and has been found very successful under favorable circumstances. The problem is, of course, to use a battery of

such size that all of the fixed and operating expenses are less than the saving in the power cost. In the considerations which follow, it is assumed that all of the charges against the battery can be covered by 13% per annum of the original battery investments. While authorities may disagree, this is a fair average figure and will serve the purpose of this report. This figure is intended to include 6% maintenance, 6% interest, and 1% for insurance, taxes, etc. On this basis, the permissable battery investment is figured without regard for other advantages from a battery installation.

A study of figure 11 shows a distinct one hour peak both morning and evening. It is obvious a battery will show the best percentage saving when it is discharged entirely on a one hour peak. To make the greatest possible saving, the battery must be discharged to its full capacity both morning and evening. It will be seen from the curve above referred to that to discharge the battery entirely on a one hour peak, the load from 7 to 8 A.M. can be cut to the value from 6 to 7 A.M. and then this same amount can be cut off the evening peak. This proposition is shown on curve 12 and is treated later as Battery Proposition No. 1.

The next logical proposition is to cut the

entire one hour peak in the evening and to cut all of the one hour peak and part of the two hour peak in the morning? This is shown curve 15 and is treated later as Battery Proposition No. 2. It is easily seen that the percentage saving can not be as large but it is very possible for the actual saving to be larger.

Any reduction in the peak below this will be entirely on a two hour basis so that the logical thing to do is to cut the evening peak down to the three hour basis and cut as much of the two hour peak as possible in the morning. This is shown in curve 17 and is treated later as Battery Proposition No. 3.

It is not the purpose of this study to deal with storage battery costs but merely to arrive at the investments warranted by the saving effected. If costs were available for the propositions treated a curve could easily be plotted showing the net saving and the battery selected which would give the greatest net saving above all expenses, both fixed and operating.

In addition to the actual money saving as a result of the reduction in the peak, there are many ways in which a storage battery can reduce the cost of operation but in which it is practically impossible to express the saving in dollars and cents Some of the uses are treated in the following

discussions. These matters are usually different in different cases and can not be treated very easily as a general subject.

STORAGE BATTERY PROPOSITION NO. I.

BATTERY PROPOSITION NO. I.

As stated in the preceding section, this propositon covers cutting off all of the peak that can be cut off both morning and evening on a one hour basis. Figure I2 shows the peak that is cut off. As shown in table 7 the load from 7 to 8 A.M. is 4766 K.W. and from 6 to 7 A.M. is 433I K.W. This gives a net amount to be cut off the total load of 435 K.W. This will give a two hour top to the morning peak as shown in the curve.

The battery to supply this power can be installed in either substation A or substation B as shown in curves I3 and I4. It will be seen from a study of these two curges that there is a sufficient amount of load being supplied from either of these substations to permit of the entire peak being cut off without the necessity of supplying any current back to the line. With this condition it is only necessary to figure on a battery of sufficient size to cut off an amount of load which when added to the transmission losses which would proportional to this load would equal the total load to be cut off.

Figuring on the transmission loss and substation loss as mentioned in a previous section, the net amount of load to be cut from the sub-

station output is 356 K.W. as shown in the calculations. This load can be cut off by the storage battery discharging in parallel with the rotary converters and taking that part of the load.

A storage battery of this kind is usually both charged and discharged through a booster and the number of cells is chosen that will float on the bus voltage. The floating voltage of a storage battery is 2.I volts per cell which gives the necessary number of cells as 286. The average voltage on discharge at the one hour rate is approximately I.78 volts per cell which gives an average voltage of 509. This means that that booster on discharge must furnish an average of 9I volts and must handle the entire battery current. The current necessary to supply 356 K.W. at 509 volts figures out to be 700. In addition to furnishing this power, the battery must furnish the losses in the booster. According to the above figures, the booster handles 700 amperes at an average voltage of 9I or 63.7 K.W. Assuming 80% efficiency or 20% loss, the loss figures out to be I2.7 K.W. or 25 amperes. Adding this to the above, it will be seen that a storage battery will be required to furnish 725 amperes for one hour.

The efficiency of a storage battery in this

kind of service can be assumed at 75%. The difference between the input and output of the battery is a loss which must be charged against the battery operation. This loss amounts to one-third of the output plus the substation and transmission losses. This is shown in the calculations and amounts to 145 K.W. per charge or on the basis of two complete charges per day, 190 K.W. per day. The maximum nunber of charges would be 600 or two per day for 300 days per year. It is very probable that conditions would not warrant the battery being discharged as much as this but this figure will be used to be conservative. This gives a total of 87,000 K.W. hours per year loss.

As the same load is cut off the peak both morning and evening, the saving will be the service charge for 435 K.W. or $6,525 per year gross. The only reduction of this with the exception of the fixed and operating expenses of the battery, is the cost of the power lost. This power will be used while the total load is low so that the service charge will not be in any way affected, so that the power lost will cost only$.004 per K.W. hr. This power cost will be $348.00 per year. Deducting this from the gross amount of $6,525 leaves a net saving of $6,177. A battery can therefore be used if the charges

against the battery are less than the net saving.

In figuring storage battery maintainence it is customary to use a figure of 13% to cover the entire charges. This is assumed to include 6% maintenance, 6% interest and 1% for insurance, taxes, etc. Firguing on this basis, the saving indicated would justify a maximum investment in storage battery of $47,500. A storage battery of the size required can easily be installed with shunt charging and discharging booster for this amount.

It will be seen from a study of the sub-station curves that the battery is not charged continuously but is used to regulate the load. The apparatus for doing this regulating cannot be properly charged against the peak proposition as this regulating is not necessary but is desirable as will be shown later. The apparatus necessary for this work will also be discussed later.

The scheme that it is proposed to use is shown in figure 20 but for a straight charge and discharge scheme all of the apparatus shown could be eliminated except the booster and a field rheostat for the booster.

BATTERY PROPOSITION NO. 2.

This proposition covers the cutting of the peak by cutting down to the two hour basis in the evening. The load from 6 to 7 P.M. is 4477 K.W. and from 5 to 6 P.M. is 3881 K.W. This gives a difference of 596 K.W. which must be taken care of by the battery. A battery to cut off this amount would have to discharge a net amount of 487.6 K.W. This would mean a net ampere hour output of 959 assuming the same average voltage as in the preceding consideration. Taking into account the booster loss, this would mean a gross ampere hour output of 993.3.

A study of figure 15 will show that the amount discharged in the hour from 6 to 7 A.M. is comparatively small so that it will not change the capacity and voltage characteristics of the battery by any appreciable amount. This is bacause the heavy discharge follows the small discharge and determines the capacity. The same amount can be cut off in the hour from 7 to 8 A.M. as in the previous consideration, namely 435 K.W. Deducting this from the total capacity as assumed above leaves 161 K.W. hours to be used on the two hour base. This would mean a discharge of 80.5 K.W. from 6 to 8 A.M. This would mean a net discharge of 515.5 K.W. from 7 to 8 A.M.

as figured on the total load input to the system.

The battery loss as figured in the preceding proposition is I19,I90 K.W. hours. The cost of this at $.004 would be $476.76 per year.

The saving in the service charge will result from the reduction in the morning peak of 5I5.5 K.W. and the reduction in the evening peak of 596 K.W. Averaging these two gives a net saving of 55I K.W. This will mean a gross saving at $I5 per K.W. per year of $8,265. Deducting the cost of the power lost, leaves a net saving of $7,788.24. This net saving would justify an investment in storage batteries of $59,800. If a storage battery of the capacity required can be installed for less than this amount, its installation would seem to be justified.

STORAGE BATTERY PROPOSITION NO. 3.

BATTERY PROPOSITION NO. 3

The third proposition is based on cutting as much of the evening peak as possible with a two hour discharge and then discharging the necessary battery to its full capacity on the morning peak. A study of figure 17 will show that the load from 5 to 7 P.M. is cut down to the load from 7 to 8 P.M. leaving the net evening peak with a three hour top.

It will also be seen that the discharge from the battery will be nearer to its two hour rating than its one hour rating so that a higher average voltage can be figured. This voltage should be at least 1.80 volts per cell or a total of 515 volts.

This scheme calls for a battery to discharge at the rate necessary to cut off 1023 K.W. from 5 to 6 P.M. and 1619 K.W. from 6 to 7 P.M. This meens a total cut in the peak of 2642 K.W. hours or a net battery discharge of 2162 K.W. hours.

The character of the morning peak is sufficiently like that in the evening to justify figuring on the battery capacity being the same both in the morning and evening. As a matter of fact, the capacity would probably be a little greater but the difference would not be of sufficient size to be important.

Figuring on the same capacity, this battery will cut the peak from 6 to 8 A.M. by 2642 K.W. hours which would mean cutting it to 3227.5 K.W. for the two hours. This would mean a cut of 1103.5 K.W. for the first hour and a cut of 1538.5 K.W. for the second hour.

The ampere hour capacity necessary to do the work outlined above including booster losses would be 4342 ampere hours. The cost of the power lost, figured in the same way as in the previous considerations, is $2114.00.

The cut of the peak in the morning is 1538.5 K.W. and in the evening 1619 K.W. giving an average of 1579 and a gross saving of $23,685. Deducting the power losses from this leaves a net saving of $21,571.00. Assuming the charges against the battery at 13%, this would justify an investment of $165,900.

The merits of these various propositions will be discussed in the next section.

GENERAL RECOMMENDATIONS & DESCRIPTION

GENERAL RECOMMENDATIONS & DESCRIPTION.

The three storage battery propositions just discussed show the three sizes of battery that should most properly be considered for the conditions as shown in the load curves.

The first proposition shows that an investment of $47,500 is justified for a battery of 286 cells with a capacity of 725 amperes for one hour. The second proposition shows an investment of $59,800 for a battery of 286 cells with a capacity of 993 amperes for one hour. The third proposition shows an investment of $165,900 for a battery capable of giving a capacity of 4342 ampere hours at approximately a two hour rate. This corresponds to about 3580 amperes for one hour.

It will be seen from these figures that the permissable investment does not increase in the same proportion that the capacity increases. This is to be expected from the nature of the load curve as the second battery discharges partly on a two hour basis and the third battery discharges more of its capacity on a two hour basis. The two hour rate is not as great as the one hour rate so that the saving for the same size battery is not as great.

From these figures it is practically certain that the first proposition will show the highest percentage on the investment from a purely peak point of view. It is probable that the second proposition will show a greater gross saving over the regular 6% interest but being distributed over a greater investment, the percentage on the investment will, in all probability, be smaller. In the last case, the gross saving above the fixed costs, will probably be less than in the second case, but it may be something, that is the proposition may be better than an even break. This is something that could not be definitely determined without exact battery costs which are not available for this consideration.

The above shows that considering the proposition from a point of view of reduction of power cost by peak reduction, the first proposition would probably be the best from on a percentage basis with the second the best from a consideration of gross return. The third proposition would probably not be justified from either of these points.

While the largest battery would seem to be eliminated by the above, there are many considerations which would warrant the installation of a battery aside from the peak question. One of these advantages is that of regulating the load.

A study of figure I3 will show what can be done in the way of regulation. The necessary discharge is shown on the peak hours as a continuous discharge at a predetermined constant rate which is the rate which was found to be necessary. It will be seen that there is a peak on the substation after the battery discharge is completed so that it would not be practical to start the charge of the battery until the load is about normal. It will be seen that the last high reading in the morning is at 8.30 and the first high one in the evening at 5.I5, so that the best time to charge the battery would be between these two points. It is desirable to keep the load constant between these two points so as to be able to operate the minimum number of rotary convertors and to operate them at the highest possible load factor and thereby the highest possible efficiency.

The curve shows this load as constant. The average of the readings between these two points was taken and to this was added the necessary power to charge the battery. Figure 20 shows the wiring diagram necessary to produce these results/ G represents the rotary convertor in the substation. The battery is shown connected directly across the main bus in series with the booster (B). As shown in the calculations, the floating voltage of a battery is about 2.I volts

per cell while the voltage on discharge is less than this and the voltage on charge more than this. The booster supplies the difference between the battery voltage and the bus voltage on discharge, the voltage adding to the battery voltage, and also the difference between the bus voltage and the voltage necessary to charge the battery, this voltage being added to the bus voltage.

If it is desired to charge the battery at a constant or appréciably constant current, the field of the booster can be regulation by an ordinary field rheostat. In this case it is desired to have the battery charge and discharge during the hours mentioned above in an amount depending on the momentary load. To do this, the field of the booster must be regulated by some device actuated by the load on the rotary convertors. The most simple way of doing this would be to put a series winding on the booster and pass the entire load through it. This scheme is correct theoreticallyand is practical in a small way but it is not flexible. When the current is large, the winding is cumbersome and it is sometimes difficult to arrange it to handle the entire load. If an attempt is made to shunt part of it, the results are not always good, as the inductance of the field varies the division of the current. The regulating must be done on rapidly fluctuating

loads so that this question of inductance is an important one. The early storage battery regulating plants were installed with this series type of booster and worked very satisfactorily so long as they were used on the particular conditions for which they were designed.

The wiring diagram above referred to shows a device which has been designed to introduce greater flexibility. This device is known as a carbon regulator. It is shown on the diagram as CR and is also shown in the cut (figure 22). This consists of piles of carbon discs arranged in two groups as indicated in the wiring diagram. These two groups are arranged one on either side of the center of the lever A. On one end of this lever is a spring (S) the tension of which is regulated by the drum (D). On the other end is a plunger moving in the coil (L) which carries the full load current. In cases where it is not practical to carry the load through a coil of this kind, a horseshoe magnet is substituted for the plunger, and this in placed directly across the main bus so that the result is the same. With an equal pull on each end of the lever, it will be seen that the pressure is the same on the two piles of discs. If the pull on either end is changed, this will throw the balance and compress one pile, or set of piles, more than the other.

leads us that this question of inductance is an important one. The early storage battery regulating plants were installed with this usual type of booster and worked very satisfactorily so long as they were used on the particular conditions for which they were designed.

The existing literature above referred to gives a device which has been employed to introduce greater flexibility. This device is known as a carbon regulator. It is shown in the diagram on [illegible] and is also shown in the cut (Figure 33). This consists of piles of carbon discs arranged in two groups as indicated in the following diagram. These two groups are arranged one on either side of the center of the lever (L). On one end of this lever is a spring (S) the tension of which is regulated by the arm (A). On the other end is a plunger moving in the coil (C) which carries the full load current. In cases where it is not practical to carry the load through a coil of this kind, a horseshoe magnet is substituted for the plunger, and this is placed directly across the main one so that the result is the same. With an equal pull on each end of the lever, it will be seen that the pressure is the same on the two piles of discs. If the pull on either end is changed, this will throw the balance and compress one pile, or set of piles, more than the other.

This means a difference in the resistance of the two sets of piles. The spring (S) can be adjusted so that it just balances any load desired so that the adjustment may be made to suit the conditions and may be varied over a wide range.

It will be seen from the diagram that the booster field is excited from a small machine or exciter (E). The field of this machine is excited through the carbon regulator. One end of field is connected to the neutral point of the battery and the other end to the neutral point of the carbon piles. The carbon piles are connected directly across the battery terminals. The number of piles used depends on the current to be passed through them. It will then be seen that any variation in the balance of the lever (A) is going to mean a flow of current through the field of the exciter and this in turn will excite the booster causing it to furnish a voltage which will cause the battery to either charge or discharge as the conditions may demand. The intermediate machine is used because it would not be practical in many cases to pass the current necessary for the booster excitation through the carbon piles.

The spring can be adjusted so as to balance any desired load. Any variation from this load will then operate the system tending to overcome the cause of the unbalance. A very small differ-

ence in load will operate the regulator so that the load is maintained within a very small margin on either side of the average and for all practical purposes, may be considered constant. While the actual momentary load has not been figured on the substation considered, it is probably safe to assume that the momentary load reaches values at least fifty per cent higher than the average values.

The load as figured from figure I3 is constant at about 593 K.W. during the day.This would mean a very fair load on a 750 K.W. rotary.

Figure I4 shows the same battery installed in substation B. The operation as shown is the same as in the previous consideration except for one point. It will be noted that the load is constant during the middle part of the day except for small indentations. When a battery is operated to regulate loads of this kind, it is desirable that it be not charged at excessive rates for any periods of appreciable length. While it is desirable to maintain the load as constant as possible on account of efficency, there is no particular harm in reducing it for short intervals.

In the wiring diagram, an electrolytic cell is shown at H. A device known as a current stop is shown at CS and is also shown in figure 23.

This current stop consists of a soft iron horseshoe magnet embracing the main battery circuit and having a pivoted armature (I). This armature is normally held away from the magnet by a spring and in that position closes a contact shortcircuiting the aluminum cell at H. When the current from the battery exceeds the amount for which the stop is set, the armature is attracted, thereby opening the contact and reducing the booster field current. The aluminum cell prevents the sparking which would be present if the field circuit were actually opened. As soon as the current is reduced by the reduction in the booster voltage, the armature is again released so that it resumes its normal position. This vibratory motion of the current stop maintains the current at a practically constant value until it has fallen below the operating current of the stop.

Figure I4 shows the operation of this stop as applied to the charging of the battery very nicely but does not show the most important function of it. The storage battery will stand almost any overload that is put on it without injury, the permissable overload being really limited by the carrying capacity of the remaining part of the circuit. The booster is designed for the maximum practical discharge of the battery

and must be protected against excessive loads. If the battery is to be used to relieve the generating apparatus of the excessive momentary loads, protecting the booster by a circuit breaker would defeat the object of the battery as the breaker would open and cut the battery off the circuit just when it was needed most. The result of this would probably mean that the breakers protecting the generating machinery would also open, thereby shutting down the substation. This would be unsatisfactory to say the least.

With the current stop in service, a breaker can be used to protect the booster but the current stop can be set to keep the current below the setting of the breaker. A winding on the horseshoe magnet of the current stop is shown at P. This coil produces a magnetic flux which is added to the main flux when the battery is charging and is opposite to it when the battery is discharging. In this way the stop can be set to open on any desired current on discharge and can be also set to operate on any charge current independently of the discharge setting.

In the case in question, the current stop would probably be set so as to allow the battery to discharge any amount up to about twice the

one hour rate of the battery. This would mean discharging up to about 712 K.W. momentarily. With an average load of 693 K.W., the fluctuations should not exceed this. The battery will take the fluctuations of load both ways up to the setting of the current stop.

It would appear from the curve (figure I4) that the load could be carried from 8.45 A.M. to 4 P.M. on one 750 K.W. rotary and be carried all of that time at an excellent load factor. If the battery were not used, it would require at least fifty per cent more capacity than this and probably more than that. The operating would be at a comparatively low load factor and the efficiency correspondingly lower. It will be seen from this that if the saving in power cost will cover the battery maintenance, the saving in the operating during the day will make the battery a decidedly good investment. The saving in the operating expense is an actual one but is hard to estimate in figures.

This same argument applies to all three of the battery propositions although the larger the battery is, the more beneficial the results are. Figures I4, I6, and I9 all show the same substation loads but show the operation of the three batteries. In the case of the last battery

proposition, the battery required to do the work outlined for it, would be too large to install in one substation as it is essential that the battery discharge be not greater than the load on the substation. If it were, it would necessitate pumping power back through the rotaries or motor generator sets onto the line and the loss in efficiency would be objectionable. For this reason it was assumed that half of the required battery would be installed in Substation A and the other half in substation B.

A glance at the three curves referred to above will show that the third proposition gives the most uniform substation load. This gives an average load during the middle of the day of 778 K.W. This could probably be carried by a 750 K.W. rotary without any difficulty as the large battery capacity used would insure the rotary from having to discharge much above the average load.

This improvement and the improvement in the load characteristics after the evening peak would justify the battery installation if the saving on the peak would carry the maintenance or the bulk of the maintenance.

The average loads for which the carbon regulator would be set and the hours during which the battery would be used for regulating purposes would have to be worked out after the plant is

in operation. The loads as figured and as shown on the curves give an idea of what can be expected from an outfit of this kind. The larger the battery used, the better regulation could be expected and the less wear there would be on the battery.

In addition to the advantage of being able to maintain a good load factor, there is the insurance value of a battery. In central station work, this insurance value is considered important enough to warrant the investment of large sums of money for this feature only. If a battery of suffiecient size could be installed on a railway line and the maintenance be carried either wholly or in a large part by the saving in power cost, its installation would certainly be warranted.

In the first battery proposition, the battery is to be installed to deliver 356 K.W. for one hour. This is assumed to be the total capacity of the battery. If the battery were called on to supply current for an emergency immediately after a complete discharge had been taken, it would not be able to safely discharge for any appreciable time at as high a rate as the one hour rate but it could safely deliver half of this amount for an hour. In the case of the smallest battery, this would be about 178 K.W.

With this amount of battery installed in only one substation and the average load on that substation around 500 K.W. during the day, the insurance value of the battery would not be very great but when it is considered that the battery installation is paid for entirely by the saving on the peak discharge and that in addition to this it is of value in regulating, the insurance value, however small, is a distinct asset.

In the case of the second size battery, much the same argument would apply. The battery capacity when fully charged would be 488 K.W. for one hour or after discharge at the one hour rate would be approximately 244 K.W. for one hour. This again is a comparatively small amount but it would be a distinct advantage.

In the case of the third battery, the capacity as figured, was 2I62 K.W. hours discharged in two hours. With this battery divided in two and installed in substations A and B, the insurance value would be great. In case of total shutdown this battery would probably be able to deliver sufficient power to operate regular service or at least such service as would be necessary, between Chicago and Riverside. It is possible also that some service might be given as far as Downers Grove. In asmuch as that is the important part of the service, being able to

maintain reasonable service for a reasonable time would be of considerable financial value. It is probable that no interruption in power supply would ever last longer than one hour and very few longer than one half hour. In central station work it is customary to figure that no important interruption will last longer than about fifteen minutes and battery capacity is installed on about this basis. In view of this the assumption with regard to this service should be safe.

All of the above considerations are based on the battery being given a complete discharge twice a day. As a matter of fact, this will not be the case. The batteries will probably not have to be discharged over fifty percent of the time and even when they are used, the discharge will not always have to be complete. In actual practice, it is found on one railway system that the battery need not be used more than about six months in the year.

The reason that the battery need not be used for peak work all of the year will be found by referring to the contract discussed in a previous section. It will be seen that there is one maximum set for the year and once this is set there is no object in cutting the load below this as there would be no saving. This peak is usually

set during the winter months and is frequently set during a period of very stormy weather. Once the peak is set, the only discharge needed from the battery is the amount required to reduce the load to the peak already set. In the case of the large battery, a discharge might be required from the battery all the year on account of the size of the load cut off. Another point in this connection is that the schedule on Saturday would probably be modified so as to suit Saturday conditions and in this way the peak would be modified so aas to eliminate it from the days which would determine the peak. In this case, the battery would not be called for much work if any. This would probably reduce the total number of days of active operation of the battery to about I25. If this could be done, the full capacity of the battery would be available on all other days for insurance purposes. The charges against the battery for the cost of power lost in charging would also be reduced. It is thus seen that all of the variations from the figures given in the previous sections tend to decrease the charges against the battery and increase the advantages of the battery.

Summing up the above, it would appear that the first battery would make an excellent investment from a purely peak load consideration. The

second battery would probably be a good investment for peak work and its advantages for regulation and reserve would eliminate any doubt. The third battery probably could not be justified on account of the saving in the power bill but the advantage of the reserve capacity would be worth more than enough to justify the installation. In addition there would be the load regulation.

While it may appear to some that no particular financial value should be attached to the insurance value of the battery, it will probably be well to note that one large railway system saw fit to make a battery installation of considerably larger size than any of the propositions in question, for reserve purposes only. If this can be done in one case, the value should be sufficient in all cases to carry part of the investment expenses.

Without the figures which are necessary to an exact analysis, it would appear that any one of the batteries could be safely purchased but that the largest one would be the most advantageous considering it from all points of view.

CALCULATIONS

EQUIPMENT & POWER CONSUMPTION.

CALCULATIONS

Assume weight of car at 90,000# unloaded

Assume capacity of car 60 passengers.

Assume average load 40 passengers

Assume weight per passenger I50# or 6000# load.

Assume speed at 33 M.P.H. schedule.

Assume maximum speed at 60 M.P.H.

K.W.hrs./car mile (previous thesis)	3.4
Watt hrs./ton mile 3.4/52.5	64.7
Assume watt hrs./ton mile motor output	64
Assume motor efficiency	85%
Watt hrs./ton mile motor input	75

K.W.hrs./car mile 75x48/I000	3.6
Average K.W./car 33(sched.speed)x3.6	II8.8
Assume average voltage at car	540
Average current II8.8/540	220 amp.
Maximum current 220 x 2.5	550 amp.

LOAD DISTRIBUTION

CALCULATIONS

Number of trains Chicago to Riverside

9-5car, I6-4car, 8I-3car, I7-2car.

Total cars	386
Total power input 386x3.6 per mile	I389.6K.W.
K.W. hours per day for section	
I389.6 x II.I	I5,424.56

Number of trains Riverside to Downers Grove

9-5 car, I0-4 car, 48-3 car, 24-2 car, I7-I car

Total cars	270
K.W. hours per mile 3.6 x 270	972
K.W. hours per day for section	
972 x(2I.2-II.I)	98I9.2

Number of trains Downers Grove to Aurora

5-4 car, 9-5 car, 32-3 car, II-2 car.

Total cars	I83
K/W. hours per mile 3.6 x I83	658.8
K.W. hours for section	
658.8 x (37.4-2I.2)	I0,672.36

Total K.W. hours per day	35,9I6.I2
Assume	36,000

SUBSTATION LOCATION
CALCULATIONS

Tatal load on system in K.W. hours per
day input to motors 36,000

Average load per substation with
four substations 9,000

Assume substation location

Substation A Western Ave. I.4 miles
SSubstation B Riverside II.I miles
Substation C Downers Grove 2I.2 miles
Substation D Eola 33.5 miles

K.W. hours per mile per day from
Chicago to Riverside I389.6

K.W. hours per day on Sub. A
I389.6 (I.4 + (II.I+I.4)/2) = 8765

K.W. hours per mile per day from
Riverside to Downers Grove 972

K.W. hours per day on Sub. B
I389.6(II.I - I.4)/2 +
972 (2I.2 - II.I)/2 = II,648

K.W. hours per mile per day from
Downers Grove to Aurora 658.8

K.W. hours per day on Sub. C
972(2I.2 - II.I)/2 +
658.8 (33.5 - 2I.2)/2 = 8,950

K.W. hours per day on Sub. D
658.8(33.5 - 2I.2)/2 + 658.8(37.4-33.5) = 66II
[illegible]

ANALYSIS of LOAD & POWER COST.

CALCULATIONS.

For the cost of power as shown in the curve (Figure 21) it was assumed that the load for 65 days in one half of the load on the other 300 days. On this basis, the load factor has been assumed as the ratio of the average load for the 300 days to the maximum load.

100% Load Factor.

Fixed charge	1 K.W. at	$15.00
Power used	24 K.W. hrs. per day for 300 days	
	12 K.W. hrs. per day for 65 days	
Total		7980 K.W. hrs.
Cost at $.004		$31.92
Total cost		$46.92
Cost per K.W. hr.		$.00587

90% Load Factor

Fixed charge	$15.00
Power used .9 x 7980	7187.2 K.W.hrs.
Cost at $.004	$28.75
Total cost	$43.75
Cost per K.W. hr.	$.00609

80% Load Factor

Fixed charge	$15.00
Power used	6384 K.W.hrs.
Cost of power	$25.54

Total cost	$40.54
Cost per K.W. hr.	$.00638

70% Load Factor

Fixed charge	$15.00
Power used	5586 K.W.hrs.
Cost of power	$22.34
Total cost	$37.34
Cost per K.W. hr.	$.00669

60% Load Factor

Fixed charge	$15.00
Power used	4788 K.W.hrs.
Cost of power	$19.15
Total cost	$34.15
Cost per K.W. hr.	$.00713

50% Load Factor

Fixed charge	$15.00
Power used	3990 K.W.hrs.
Cost of power	$15.96
Total cost	$30.96
Cost per K.W. hr.	$.00776

40% Load Factor

Fixed charge	$15.00
Power used	3192 K.W.hrs.
Cost of power	$12.77
Total cost	

Total cost	$27.77
Cost per K.W.hr.	$.0087

30% Load Factor

Fixed charge	$15.00
Power used	2394 K.W.hrs.
Cost of power	$ 9.58
Total cost	$24.58
Cost per K.W. hr.	$.01025

20% Load Factor

Fixed charge	$15.00
Power used	1596 K.W. hrs.
Cost of power	$ 6.38
Total cost	$21.38
Cost per K.W. hr.	$.01338

10% Load Factor

Fixed charge	$15.00
Power used	798 K.W.hrs.
Cost of power	$ 3.19
Total cost	$18.19
Cost per K.W. hr.	$.0228

5% Load Factor

Fixed charge	$15.00
Power used	399 K.W.hrs.
Cost of power	$ 1.60
Total	

Total cost	$16.60
Cost per K.W. hr.	$.0416

4% Load Factor

Fixed charge	$15.00
Power used	319 K.W.hrs.
Cost of power	$ 1.28
Total cost	$16.28
Cost per K.W.	$.0510

3% Load Factor

Fixed charge	$15.00
Power used	239 K.W.hrs.
Cost of power	$ .96
Total cost	$15.96
Cost per K.W. hr.	$.0667

2% Load Factor

Fixed charge	$15.00
Power used	160 K.W.hrs.
Cost of power	$ .64
Total cost	$15.64
Cost per K.W. hr.	$.098

1% Load Factor

Fixed charge	$15.00
Power used	80
Cost of power	$ .32
Total cost	$15.32
Cost per K/W. hr.	$.192

The total load per day for the system is obtained by adding the loads shown in table 7. These figures give a total of 48,140 K.W. hrs. Assuming this load for 300 days and half of this for 65 days, we get a total for the year of 16,006,550 K.W.hrs.

The cost of this at $.004	$64,026.20
The maximum morning load is	4766 K.W.
The maximum evening load is	4477 K.W.
Average	4621.5 K.W.
Service charge at $15.00	$69,322.50
Total cost of power	$133,348.70
Cost per K.W. hr.	$.00833

BATTERY PROPOSITION NO. I.

CALCULATIONS

Total average load 7A.M. to 8 A.M.	4766 K.W.
6 A.M. to 7 A.M.	433I K.W.
Amount to be cut off	435 K.W.
Battery needed to give 435 K.W. less transmission losses or 435 x 9/II	356 K.W.
Average floating voltage per cell	2.I
Number of cells 600/2.I	286
Average voltage per cell at I hour rate	I.78
Average voltage for battery 286xI.78	509
Ampere hours (net) 356000/509	700
Voltage supplied by booster 600 - 509	9I
K.W. of booster 700x9I/I000	63.7
Loss in booster at 80% efficiency	I2.7 K.W.
Amperes from battery for booster loss I2700/509	25
Ampere hours gross	725
Assume battery efficiency at	75%
Loss in percentage of output	33 I/3%
Power to supply loss for two charges per day and 300 days per year 356xIIx300x2/(9x3)	87,000 K.W.hrs
Cost of power loss per year at $.004	$348.00
Saving is service charge 435xI5	$6525.00
Net saving in power cost(difference)	$6I77.00
Permissable investment(6I77/I3)I00	$47,500.00

BATTERY PROPOSITION NO. 2.

CALCULATIONS

Total average load 6P.M. to 7P.M.	4477 K.W.
5P.M. to 6P.M.	388I K.W.
Amount to be cut off	596 K.W.
Battery needed to give 596 K.W. less transmission losses or 596 x 9/II	488 K.W.
Number of cells (as before)	286
Average voltage (as before)	509
Ampere hours (net)488000/509	959
K.W. of booster 959x9I/I000	87.2
Loss in booster at 80% efficiency	I7.4 K.W.
Ampere hours loss I7400/509	34.3
Total ampere hour output	993.3
Battery capacity assumed same on morning discharge	
Discharge 7 A.M. to 8 A.M.(as before)	435K.W.
Additional discharge 6 A.M. to 8 A.M. (596 - 435)/2	80.5 K.W.
Total discharge 7 A.M. to 8 A.M.	5I5.5 K.W.
Power loss to supply loss for two charges per day and 300 days per year 596x300x2xII/(9x3)	II9,I90 K.W.hrs.
Cost of power loss at $.004	$476.76
Average reduction in peak (596 - 5I5.5)/2	55IK.W.
Saving in sservicecharge 55IxI5	$8265.00
Net saving	$7788.24
Permissable investment 7788.24/.I3	$59,800.00

BATTERY PROPOSITION NO. 3.

CALCULATIONS

Total average load	6 P.M. to 7 P.M.	4477 K.W.
	5 P.M. to 6 P.M.	3881 K.W.
	7 P.M. to 8 P.M.	2858 K.W.
Amount to cut off	6 P.M. to 7 P.M.	1619 K.W.
	5 P.M. to 6 P.M.	1023 K.W.
Total K.W. hours cut off		2642
Battery needed to give 1023 K.W. less transmission losses for first hour 1023 x 9/11		837 K.W.
Battery to give for second hour 1619 x 9/11		1325
Number of cells (as before)		286
Average voltage per cell at this rate of discharge can be assumed at		1.80
Average voltage of battery		515.
Ampere hours (net) 837000/515(first hour)		1622
Ampere hours(net) 1325000/515(second hour)		2580
Booster loss(first hour) 85x1622x.20		55 amp.hrs
Booster loss(second hour)85x2580x.20		85 amp.hrs
Total ampere hours first hour		1677
	second hour	2665
Total ampere hours for two hours		4342
Total K.W. hours for two hours		2162

Assume that battery will give same capacity on morning peak

Total reduction to be made	2642 K.W.hrs

Discharge 7 A.M. to 8 A.M. (as before)	435 K.W.
Discharge 6 A.M. to 8 A.M.(2642 - 435)/2	1103.5KW
Total discharge 6 A.M. to 8 A.M.	1538.5KW
Battery loss 2162x2x300x11/(9x3)	528,500 KW hrs
Cost of power loss	$2,114.00
Average reduction in peak(1619 - 1538)/2	1579 K.W.
Total saving in service charge	$23,685.00
Net saving	$21,571.00
Permissable investment	$165,000.00

TABLES

TABLE I

ANALYSIS OF GRAPHICAL TIME TABLE

First figure shows distance in miles from Chicago and second figure shows number of cars.

I2.00 Mid.	3I.6/3,I4.2/2,II.I/2,
I5	37.4/2,22.3/2,5.4/2
30	33.5/2,25.7/2,0/2
45	I6.4/2,6.8/2,
I.00	I3.8/2,I0.7/2
I5	20.5/2,3.8/2,
30	3I.3/2,

5.45	33.5/5,I9.3/3,
6.00	37.4/5,22.3/5,I2/7/3,9/3,0/4,
I5	26.5/5,II.I/5,7/4,4.7/6,2.2/3,
30	29.8/4,2I.2/3,20.2/4,I4/8/5,I3.I/3, 8.9/3,5.3/3,I.I/5
45	34/5,30.3/4,I9.6/7,I4.6/3,II/3, 3.7/5,2.4/3,
7.00	37.4/5,22.7/5,I6.8/4,8.0/3,6.5/4, 5.5/3,0/5
I5	26.5/5,I9.4/4,II.I/9,7.5/3,6.5/3, 3/3,.7/3,
30	37.4/4,I9.6/5,I5.4/5,I3/4,II.7/3, 9.I/3,5.I/4,2.2/4,I/4/5,/8/3
45	30/5,26/4,I8.3/3,9.I/3,5/4,3.5/5,2/3,
8.00	37.4/3,2I.2/4,I6/4,9.2/4,2.3/3,0/4
I5	26.5/3,I4/4,6.7/4,5.3/7,2.2/4,0/3

TABEE I (continued)

8.30	I9.7/4,I7.6/I,I5.5/3,I2/3,6.5/7
45	30/4,I7.5/3,II.5/I,3.3/3
9.00	37.4/3,2I.2/3,I5.I/I,6.I/3,0/3
I5	26/3,I4/3,6.7/3,3.3/3
30	I9.4/3,I8.2/I,I5.4/3,II.8/3,6.5/3,3.3/3
45	30.3/3,I7.8/3,I2.3/I,9.6/3,3/3,
I0.00	37.4/3,2I.2/3,I3.8/I,8.5/3,0/3
I5	26/3I9.7/I,I3/3,6.9/3,3/3,I.4/3
30	2I.2/I,20/3,I5.2/3,II.7/3,6.9/3,I/3
45	3I/3,I8/3,I4.2/I,8.2/3,3/3,
II.00	37.4/3,2I.2/3,II.8/I,I0.4/3,0/3
I5	26/3,I7.8/I,I3.8/3,7/3,4.2/3,3.I/3
30	20.2/3,I5.5/3,I2/3,6.5/3
45	30.5/3,I7.8/3,I7.2/I,5/3,3/3,
I2.00 Noon	37.4/3,2I.2/3,0/3,
I5	25.6/3,I3.8/3,7.2/3,6.8/3,3.8/3,0/3,
30	I9/3,I8.3/I,I5.2/3,I2.3/3,6.9/3,6.5/3, .4/3
45	29.6/3,I8.7/3,I2.5/I,3/3,
I.00	37.4/3,2I.2/3,I5.2/I,6.9/3,0/3,
I5	25.7/3,I3.9/3,6.8/3,3.3/3,
30	2I.2/I,I8.8/3,U5.6/3,I2.3/3,6.7/3,2.2/3
45	29.6/3I8.5/3,I3.8/I,9.4/3,3/3,
2.00	37.4/3,2I.2/3,I3.8/I,8.8/3,0/3,
I5	26/3,20.4/I,I3.8/3,7/3,3.7/3,I.4/3,
30	I9.2/3,I5.4/3,II.9/3,6.5/3,.6/3,
45	30/3,I8.5/3,I5.7/I,7.5/3,3/3,

3.00	37.4/3,2I.2/3,II.I/I,II.I/3,0/3,
I5	25.5/3,I6/I,I3.8/3,6.5/3,5/3,4/3,
30	I9.2/3,I5/3,I2.4/3,6.5/3,
45	29.5/3,I9.5/I,I8.4/3,3.8/3,3/3,
4.00	37.4/3,2I.2/3,I2.8/I,I0.8/3,0/3,
I5	25.7/3,I4.2/I,I3.8/3,7.8/3,7/3,3.2/3,
30	20.4/I,I9/3,I5.4/3,I2/3,6.5/3,4.5/3, I/3,
45	29.5/3,I8.5/3,I3.I/I,II.I/3,2.8/3,
5.00	37.4/3,2I.2/3,I4.5/I,7.3/3,0/3,
I5	25.8/3,I3.8/3,7.5/3,5.3/3,I.4/3,
30	2I.2/I,I9/3,I4.6/3,9.6/3,6.5/3, 3.5/5,2.4/4,0/4,
45	29.5/3,I5.4/8,I4.3/I,9.8/4,6.7/4, 2.7/3,I.2/5,.6/4,
6.00	37.4/3,26/5,2I.2/3,I3.8/I,II.I/5, 9.2/4,7.5/4,3/4,0/5,
I5	25.8/3,22.6/5,I3.8/3,II.8/4,7/5, 5/4,2/4,I/3,
30	34/5,I9/5,I7.6/4,I5.3/3,9.3/3, 6.4/3,3.I/3,0/5,
45	30/5,I5.4/3,I0.I/3,6.7/5,3/3,I/3,
7.00	29/2,I9/8,9.6/3,8.3/3,0/4,
I5	29.5/5,I9.4/2,I5.5/3,I2.5/3,I0/3, 7/4,I.4/3,I/3,
30,	I9.4/4,8.2/3,6.3/2,4.5/3,3.5/6,
45	29.5/4,I2/3,3/3,
8.00	37.4/2,I8.3/3,I0.I/3,I/2,0/3,

8.I5 P.M.	26/2,II.I/2,6/3,
30	22.6/2,I4.7/2,I3.9/3,I.4/2,
45	34/2,9/2,3/2,
9.00	37.4/2,2I.2/2,9.8/2,0/2,
I5	26/2,I3.8/2,6/2,3.5/2,
30	I6.4/2,I4/2,6.5/2,0/3,
45	2I.2/2,II/2,6/2,
I0.00	32/2,3.6/2,0/2,
I5	32.5/2,6.5/2,
30	22/2,I3.8/2,0/2,
45	2I/2,I4.2/2,6.5/2,
II.00	32.5/2,8.8/2,0/3,
I5	37.4/2,6.5/3,I/4/2,
30	26/3,I4/3,3.3/3,0/2,
45	2I.5/3,I6.7/2,I0.2/3,6.2/3,

TABLE 2.

CURRENT OUTPUT FROM SUBSTATIONS AND TOTALS.

Time	Sub.A	Sub.B	Sub.C	Sub.D	Total
I2.00Mid.		757	225	558	I540
I5	258	I82	40I	479	I320
30	440		279	60I	I320
45	205	444-	23I		880
I.00	I8	745	II7		880
I5	33I	I40	409		880
30			79	36I	440
5.45		I24	536	II00	I760
6.00	I023	I072	II06	II99p	4400
I5	I837	2I23	670	430	5060
30	I576	2I57	2253	6I4	6600
45	I430	I650	I769	I75I	6600
7.00	2II0	I574	I47I	I225	6380
I5	I736	204I	I348	475	5600
30	3243	3099	I578	880	8800
45	2I48	I342p	I29I	II59	5940
8.00	I65I	I22I	I308-	660	4840
I5	3I05	I482	626	287	5500
30	740	I982	I238		3960
45	53I	573	686	630	2420
9.00	I000	453	747	660	2860
I5	845	88I	656	258	2640
30	9II	I592	I0I7		3520
45	646	II03	6II	500	2860
I0.00	838	643	7I9	660	2860
I5	I490	935	837	258	3520
30	950	I420	II50		3520
45	750	942	668	500	2860
II.00	720	643	837	660	2860
I5	I300	I230	730	260	3520
30	290	I420	930		2640
45	970	650	740	500	2860
I2.00	660		660	660	I980
I5	I750	I300	650	260	3960
30	I260	I927	993		4I80
45	550	520	630	500	2200
I.00 PM	950	500	750	660	2860
I5	830	900	650	260	2640
30	896	I554	I070		3520
45	670	I03I	659	500	2860

TABLE 2.

Time	Sub.A	Sub.B	Sub.C	Sub.D	Total
2.00	820	66I	7I9	660	2860
I5	I290	920	850	260	3520
30	950	I500	850		3300
45	795	645	480	940	2860
3.00	660	880	660	660	2860
I5	I200	I305	755	260	3520
30	290	I360	470	520	2640
45	I033	544	783	500	2860
4.00	687	833	690	660	2860
I5	I060	I482	7I8	260	3520
30	I400	I727	I053		4I80
45	550	II67	643	500	2860
5.00	920	546	734	660	2860
I5	I354	I036	650	260	3300
30	2940	I770	IOIO		5720
45	307I	2489	I034	446	7040
6.00	2335	2666	I389	I090	7480
I5	2505	2320	I624	37I	6820
30	2085	I93I	I704	II00	6820
45	I780	I680	590	790	4840
7.00	II70	I4I0	I540	280	4400
I5	I765	2II8	I097	740	5720
30	I897	I338	725		3960
45	550	7I0	345	595	2200
8.00	II70	780	470	440	2860
I5	345	755	270	I70	I540
30	440	760	730	50	I980
45	5I0	370		440	I320
9.00	500	380	440	440	I760
I5	575	630	385	I70	I760
30	870	754	356		I980
45	230	650	440		I320
I0.00	780	I00	50	390	I320
I5	230	2I0	35	405	880
30	440	322	530	28	I320
45	230	5I5	575		I320
II.00	755	345	35	405	I540
I5	750	350		440	I540
30	970	540	650	260	2420
45	409	II07	904		2420

TABLE 3.

LOAD ON SUBSTATION A.

Time	Amp. 600 V.	K.W. Output	K.W. Input	K.W.Av. Output	K.W.Av. Input
I2.00Mid	0	0	0	0	
I5	258	I55	I72		
30	440	264	294	I37	I52
45	205	I23	I37		
I.00	I8	II	I2		
I5	33I	I97	22I	82	9I
---30-	0				
5.45A.M.	0			204	227
6.00	Io23	6I4	682		
I5	I837	II02	I225		
30	I576	946	I050	963	I069
45	I430	858	955		
7.00	2II0	I266	I405		
I5	I736	I042	II60		
30	3243	I946	2I60	I35I	I50I
45	2I48	I289	I432		
8.00	I65I	99I	II00		
I5	3I05	I863	2070		
30	740	444	494	856	95I
45	53I	3I9	354		
9.00	I000	600	667		
I5	845	507	563		
30	9II	547	608	499	554
45	646	388	430		
I0.00	838	503	560		
I5	I490	894	994		
30	950	570	635	596	662
45	750	450	500		
II.00	720	432	480		
I5	I300	780	867		
30	290	I74	I93	488	542
45	970	582	647		
I2.00	660	396	440		
I5	I750	I050	II65		
30	I260	756	840	654	727
45	550	330	367		
I.00	950	570	634		
I5	830	498	553		
30	896	538	598	492	547
45	670	402	446		

TABLE 3.

LOAD ON SUBSTATION A.

Time	Amp. 600 V.	K.W. Output	K.W. Input	K.W.Av. Output	K.W.Av. Input
2.00	820	492	547		
15	1490	894	993		
30	950	570	634	597	663
45	795	477	530		
3.00	660	396	440		
15	1200	720	800		
30	290	174	193	479	532
45	1033	620	688		
4.00	687	412	458		
15	1060	636	707		
30	1400	840	933	572	636
45	550	330	367		
5.00	920	552	614		
15	1354	812	902		
30	2940	1764	1960	1350	1500
45	3071	1843	2050		
6.00	2335	1401	1559		
15	2505	1503	1671		
30	2085	1251	1390	1219	1354
45	1780	1068	1185		
7.00	1170	702	780		
15	1765	1059	1174		
30	1897	1138	1261	805	895
45	550	330	367		
8.00	1170	702	780		
15	345	207	230		
30	440	264	294	319	355
45	510	306	340		
9.00	500	300	333		
15	575	345	372		
30	870	522	580	345	383
45	230	138	153		
10.00	780	468	520		
15	230	138	153		
30	440	264	293	250	278
45	230	138	153		
11.00	755	453	504		
15	750	450	500		
30	970	582	647	376	418
45	409	247	275		

TABLE 4.

LOAD ON SUBSTATION B.

Time	Amp. 600 V	K.W. Output	K.W. Input	K.W.Av Output	K.W.Am. Input
I2.00Mid	757	454	505	207	230
I5	I82	I09	I2I		
30					
45	444	266	296		
I.00	745	447	497	I23	I37
I5	I40	84	93		
30					
5.45AM	I24	74	83	I088	I209
6.00	I072	643	7I5		
I5	2I23	I274	I4I6		
30	2I57	I294	I438		
45	I650	990	II00		
7.00	I574	944	I049	I182	I3I3
I5	204I	I225	I36I		
30	3099	I859	2066		
45	I342	805	895		
8.00	I22I	733	8I4	73I	8I2
I5	I482	889	988		
30	I982	II89	I320		
45	573	344	382		
9.00	453	272	302	6I8	687
I5	88I	529	587		
30	I592	955	I06I		
45	II03	662	735		
I0.00	643	386	429	59I	657
I5	935	56I	623		
30	I420	852	947		
45	942	565	628		
II.00	643	386	429	544	604
I5	I230	738	820		
30	I420	852	947		
45	650	390	433		
I2.00				599	666
I5	I300	780	867		
30	I927	II56	I283		
45	520	3I2	347		
I.00PM	500	300	333	605	672
I5	900	540	600		
30	I554	932	I036		
45	I03I	6I9	663		

TABLE 4.

LOAD ON SUBSTATION B.

Time	Amp. 600 V	K.W. Output	K.W. Input	K.W.Av Output	K.W.Av Input
2.00PM	66I	397	44I		
I5	920	552	6I3		
30	I500	900	I000	565	639
45	645	387	430		
3.00	880	528	587		
I5	I305	783	870		
30	I360	8I6	907	609	677
45	544	326	363		
4.00	823	494	549		
I5	I482	889	988		
30	I727	I036	II5I	749	832
45	II67	700	734		
5.00	546	328	364		
I5	I036	622	69I		
30	I770	I062	II80	I035	II50
45	2489	I493	I659		
6.00	2666	I600	I777		
I5	2320	I392	I547		
30	I93I	II59	I287	I196	I328
45	I680	I008	II20		
7.00	I4I0	846	940		
I5	2II8	I27I	I4I2		
30	I338	803	892	789	877
45	7I0	426	473		
8.00	780	468	520		
I5	755	453	503		
30	760	456	507	370	4II
45	370	222	247		
9.00	380	228	253		
I5	630	378	420		
30	754	452	503	34I	379
45	650	390	433		
I0.00	I00	60	67		
I5	2I0	I26	I40		
30	322	I93	2I3	I90	2II
45	5I5	309	343		
II.00	345	207	230		
I5	350	2I0	233		
30	540	324	360	383	425
45	II07	664	738		

TABLE 6.

LOAD ON SUBSTATION C.

Time	Amp. 600 V	K.W. Output	K.W. Input	K.W.AV Output	K.W.Av Input
I2.00Mid	225	I35	I50	I59	I76
I5	40I	24I	267		
30	279	I53	I70		
45	23I	I39	I54		
I/00	II7	70	78	I3I	I46
I5	409	245	273		
30	79	47	53		
5.45AM	536	322	357	436	483
6.00	II06	664	737		
I5	670	402	447	893	992
30	2253	I337	I485		
45	I769	I06I	II79		
7.00	I47I	883	98I	842	935
I5	I348	809	899		
30	I578	947	I052		
45	I29I	775	86I		
8.00	I308	785	872	537	597
I5	626	376	4I8		
30	I238	743	825		
45	686	4I2	457		
9.00	747	448	498	460	5II
I5	656	394	437		
30	I0I7	6I0	678		
45	6II	397	44I		
I0.00	7I9	43I	479	5I5	572
I5	837	502	558		
30	II50	690	767		
45	6668	40I	445		
II.00	837	502	558	473	525
I5	730	438	487		
30	930	558	620		
45	740	444	494		
I2.00	660	396	440	446	496
I5	650	390	433		
30	993	596	662		
45	630	378	420		
I.00PM	750	450	500	467	5I9
I5	650	390	433		
30	I070	642	7I3		
45	659	395	439		

TABLE 5.

LOAD ON SUBSTATION C.

Time	Amp. 600 V	K.W. Output	K.W. Input	K.W.Av Output	K.W.Av Input
2.00PM	7I9	43I	479	430	478
I5	850	5I0	567		
30	850	5I0	567		
45	480	288	320		
3.00	660	396	440	402	447
I5	755	453	503		
30	470	282	3I3		
45	783	470	522		
4.00	690	4I4	460	472	524
I5	7I8	43I	469		
30	I053	632	702		
45	643	386	54I		
5.00	734	440	489	558	620
I5	650	390	433		
30	I0I0	606	65I		
45	I034	620	689		
6.00	I389	833	926	807	897
I5	I624	974	I083		
30	I704	I022	II36		
45	590	354	393		
7.00	I540	924	I027	489	543
I5	I097	658	79I		
30	725	435	483		
45	345	207	230		
8.00	470	282	3I3	2I8	242
I5	270	I62	I80		
30	730	438	487		
45					
9.00	440	264	29I	2I4	238
I5	385	23I	257		
30	356	2I5	239		
45	440	264	293		
I0.00	50	30	33	I79	I98
I5	35	2I	23		
30	530	3I8	353		
45	575	345	383		
II.00	35	2I	23	253	28I
I5					
30	650	390	433		
45	904	542	603		

TABLE 6.

LOADOON SUBSTATION D.

Time	Amp.; 600 V	K?W? Output	K.W. Input	K.W.Av Output	K.W.Av Input
I2.00	558	335	372		
I5	479	287	3I9		
30	60I	36I	40I	204	227
45					
I.00					
I5					
30	36I	2I7	24I	87	96
5.45	II00	660	733		
6.00	II99	7I9	799	680	755
I5	4430	258	287		
30	6I4	368	409	60I	668
45	I75I	I05I	II67		
7.00	I225	735	8I7		
I5	475	3II	346		
30	880	528	587	525	583
45	II59	695	773		
8.00	660	396	440		
I5	287	I72	I9I		
30				234	260
45	630	378	420		
9.00	630	378	420		
I5	258	I55	I72		
30				2II	234
45	500	300	333		
I0.00	660	396	440		
I5	258	I55	I72		
30				2I2	236
45	500	300	333		
II.00	660	396	440		
I5	260	I56	I74		
30				2I3	237
45	500	300	333		
I2.00	660	396	440		
I5	260	I56	I73		
30				2I3	237
45	500	300	333		
I.00PM	660	396	440		
I5	260	I56	I73		
30				2I3	237
45	500	300	333		

TABLE 6.

LOAD ON SUBSTATION D.

Time	Amp. 600 V	K.W. Output	K.W. Input	K.W.Av Output	K.W.Av Input
2.00	660	396	440	[illegible]	
I5	260	I56	I73	I05	
30				279	3I0
45	940	564	623		
3.00	660	396	440		
I5	260	I56	I73		
30	520	3I2	347	29I	323
45	500	300	333		
4.00	660	396	440		
I5	260	I56	I73		
30				2I3	237
45	500	300	333		
5.00	660	396	440		
I5	260	I56	I73		
30				232	258
45	446	268	275		
6.00	I090	654	727		
I5	37I	223	247		
30	II00	660	733	442	49I
45	796	474	527		
7.00	280	I68	I87		
I5	740	444	493		
30				254	282
45	595	357	397		
8.00	440	264	293		
I5	I70	I02	II3		
30	50	30	33	I67	I86
45	440	264	293		
9.00	440	264	293		
I5	I70	I02	II3		
30				88	98
45					
I0.00	390	234	260		
I5	405	243	270		
30	28	I7	I9	I25	I39
45					
II.00	405	243	270		
I5	440	264	293		
30	260	I56	I73	I77	I97
45					

TABLE 7.

INPUT TO EACH SUBSTATION
TOTAL INPUT TO SUBSTATIONS
TOTAL INPUT TO SYSTEM

Time	A	B	C	D	Total Subs	Total System	Average
12.00	.	505	150	372	1027	1130	
15	172	121	267	319	879	967	
30	294		170	401	865	952	863
45	137	296	154		587	646	
1.00	12	497	78		587	646	
15	221	93	273		587	646	
30			53	241	294	323	517
5.45AM		83	357	733	1173	1290	1935
6.00	682	715	737	799	2933	3226	
15	1225	1416	447	287	3375	3713	
30	1050	1438	1485	409	4382	4820	4331
45	955	1100	1179	1167-	4401	4841	
7.00	1405	1049	981	817	4252	4677	
15	1160	1361	899	346	3766	4143	
30	2160	2066	1052	587	5865	6452	4766
45	1432	895	861	773	3961	4357	
8.00	1100	814	872	440	3226	3549	
15	2070	988	418	191	3667	4034	
30	494	1320	825		2539	2903	2881
45	354	382	457	420	1613	1774	
9.00	667	302	498	420	1887	2076	
15	563	587	437	172	1759	1935	
30	608	1061	678		2347	2581	2184
45	430	735	441	333	1939	2132	
10.00	560	429	479	440	1908	2098	
15	994	623	558	172	2347	2582	
30	635	947	767		2349	2584	2395
45	500	628	445	333	1906	2097	
11.00	480	429	558	440	2307	2538	
15	867	820	487	173	2337	2571	
30	193	947	620		1760	1936	2150
45	647	433	494	333	1907	2098	
12.00	440		440	440	1320	1452	
15	1165	867	433	173	2638	2902	
30	840	1283	662		2785	3064	2339
45	367	347	420	333	1467	1614	
1.00PM	634	333	500	440	1907	2098	
15	553	600	433	173	1759	1935	
30	598	1036	713		2347	2582	2165
45	446	663	439	333	1881	2069	

TABLE 7.

Time	A	B	C	D	Total Subs	Total System	Average
2.00	547	44I	470	440	I867	2054	
I5	993	6I3	567	I73	2346	2580	
30	634	I000	567		220I	242I	2294
45	530	430	320	627	I907	2098	
3.00	440	587	440	440	I907	2098	
I5	800	870	503	I73	2346	2580	
30	I93	907	3I3	347	I760	I936	2I78
45	688	363	522	333	I906	2097	
4.00	458	549	460	440	I907	2098	
I5	707	988	469	I73	2337	257I	
30	933	II5I	702		2786	3065	2452
45	367	734	45I	333	I885	2074	
5.00	6I4	364	489	440	I907	2098	
I5	902	69I	433	I73	2I99	24I9	
30	I960	II80	65I		379I	4I70	388I
45	2050	I659	689	275	4673	5I40	
6.00	I559	I777	926	727	4989	5487	
I5	I67I	I547	I083	247	4548	5002	
30	I390	I287	II36	733	4546	500I	4477
45	II85	II20	393	527	3225	3547	
7.00	780	940	I027	I87	2934	3227	
I5	II74	I4I2	79I	493	3870	4257	
30	I26I	892	483		2636	2899	2858
45	367	473	230	397	I467	I6I4	
8.00	780	520	3I3	293	I906	2097	
I5	230	503	I80	II3	I026	II29	
30	294	507	487	33	I32I	I453	I3I0
45	340	247		293	880	968	
9.00	333	253	29I	293	II70	I287	
I5	372	420	257	II3	II62	I278	
30	580	503	239		I322	I454	I207
45	I53	433	293		879	967	
I0.00	520	67	33	260	880	968	
I5	I53	I40	23	270	586	645	
30	293	2I3	353	I9	878	966	907
45	I53	343	383		879	967	
II.00	504	230	23	270	I027	II30	
I5	500	233		293	I026	II29	
30	647	360	433	I73	I6I3	I774	I453
45	275	738	603		I6I6	I778	

AURORA
Western Springs
150
100
50
ELEVATION IN FEET
2000
800

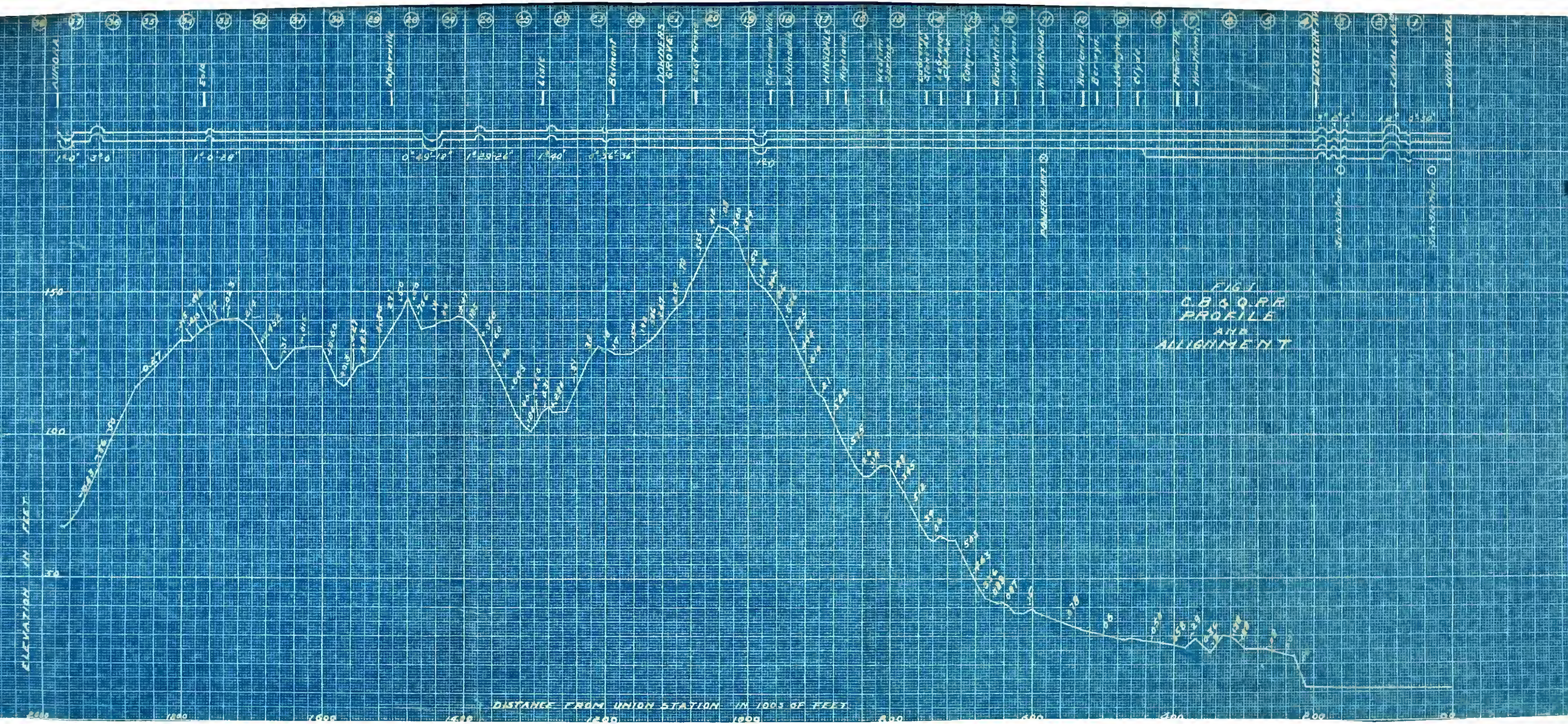
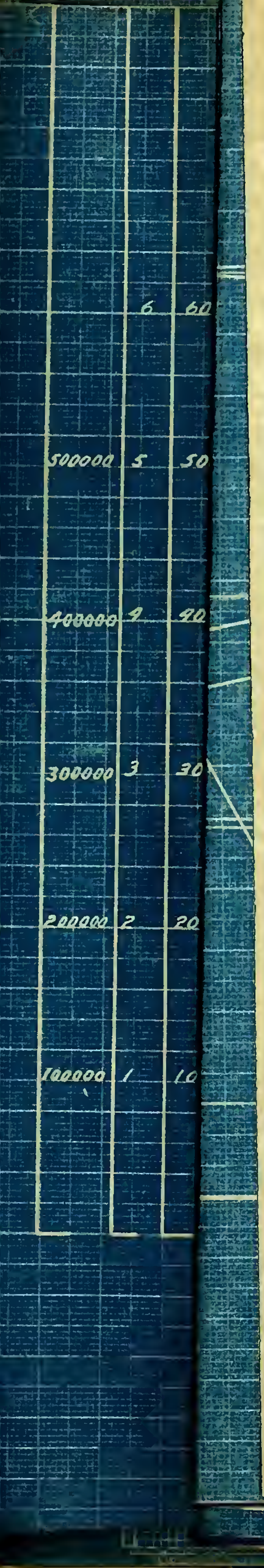
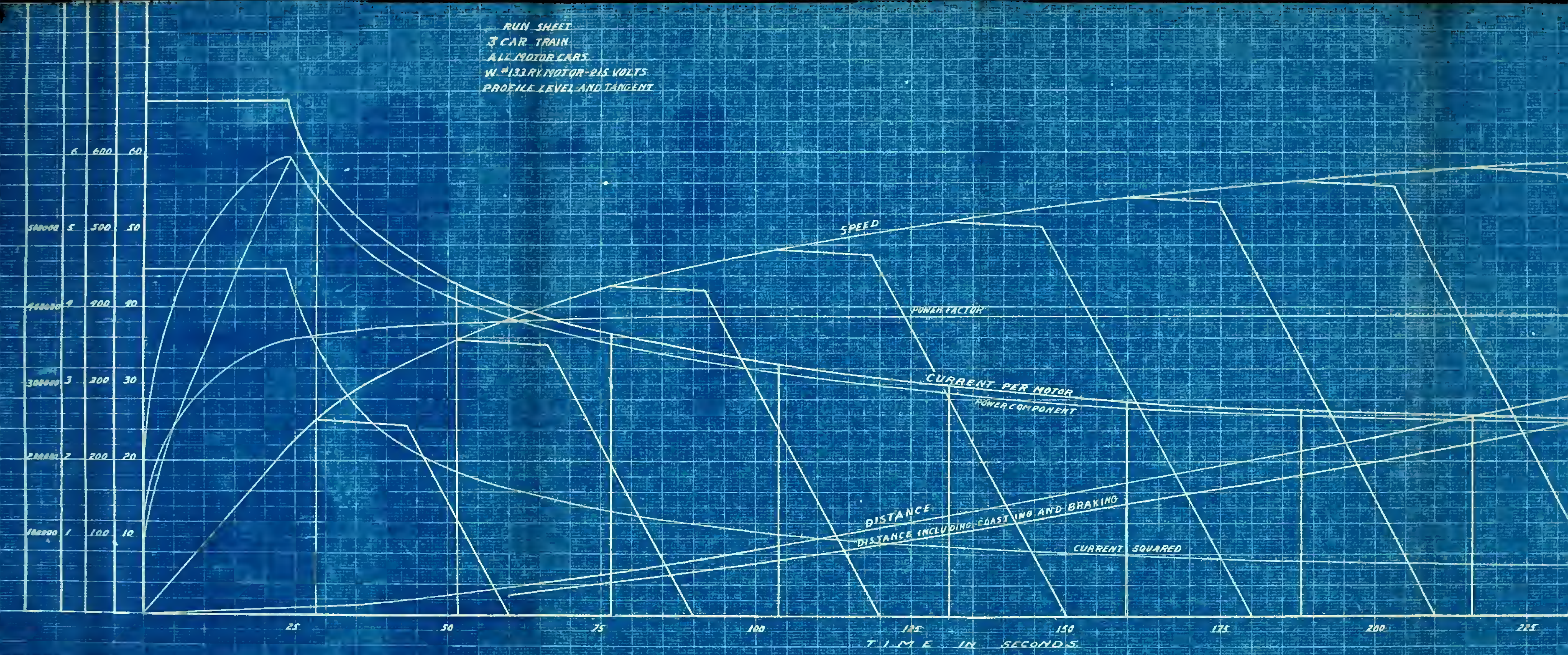
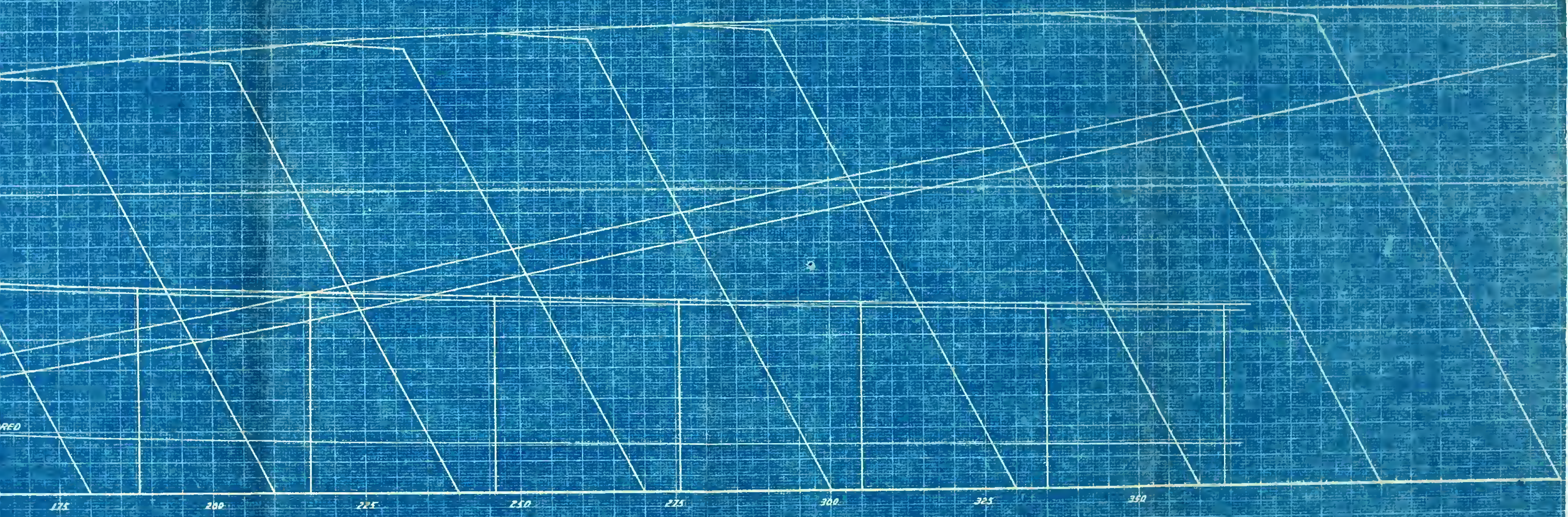


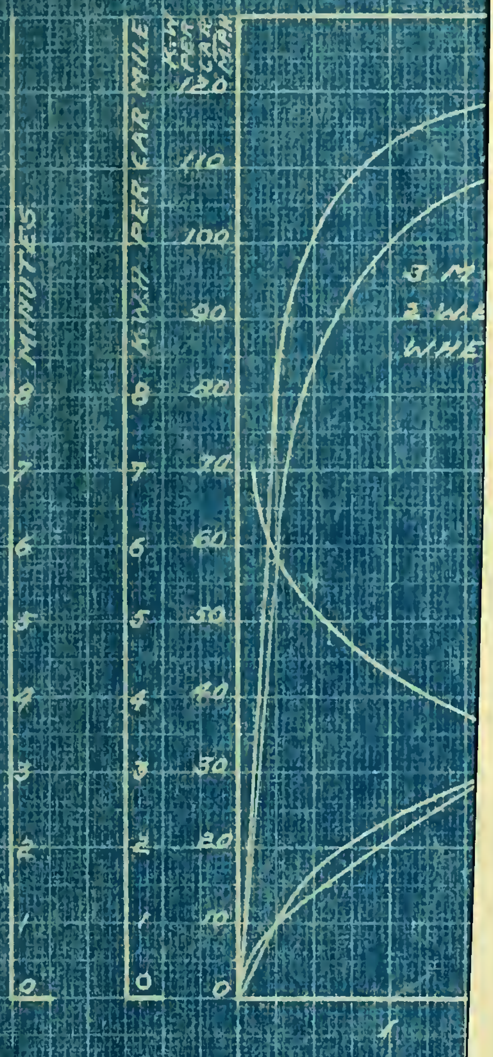
FIG. 1
C.B.&Q.R.R.
PROFILE
AND
ALIGNMENT


6
60
500000
5
50
400000
4
40
300000
3
30
200000
2
20
100000
1
10



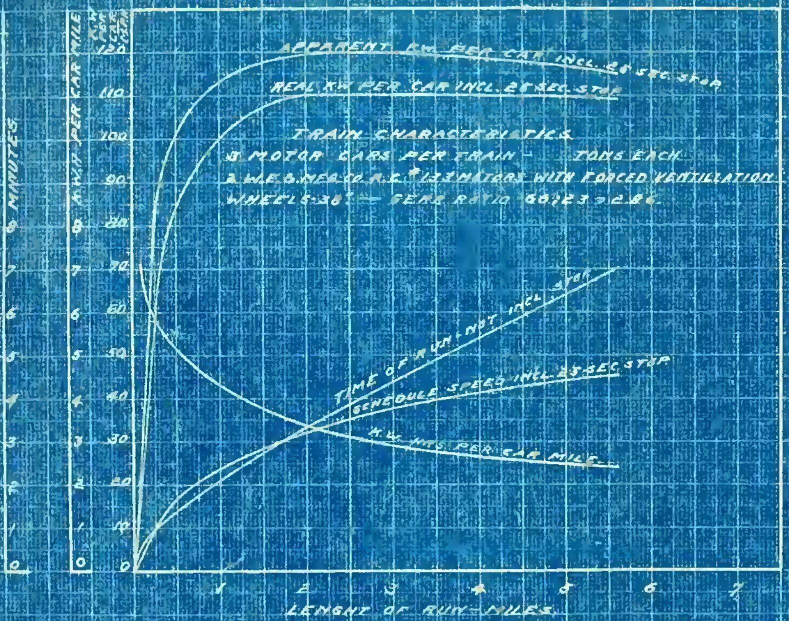
CURVE SHEET #3


RED
175
200
225
250
275
300
325
350



MINUTES
K.W.H. PER CAR MILE
K.W. PER CAR
M.P.H.
0
1
2
3
4
5
6
7
8
10
20
30
40
50
60
70
80
90
100
110
J. M
2 WE
WHE
1

2
7
8
9
10
11



TRAIN CHARACTERISTICS

8 MOTOR CARS PER TRAIN — TONS EACH

2 W.E.&M.Co. No. 300 R.C. #133 MOTORS WITH FORCED VENTILATION

WHEELS 36" — GEAR RATIO 66:23 = 2.86

CURVE SHEET #4

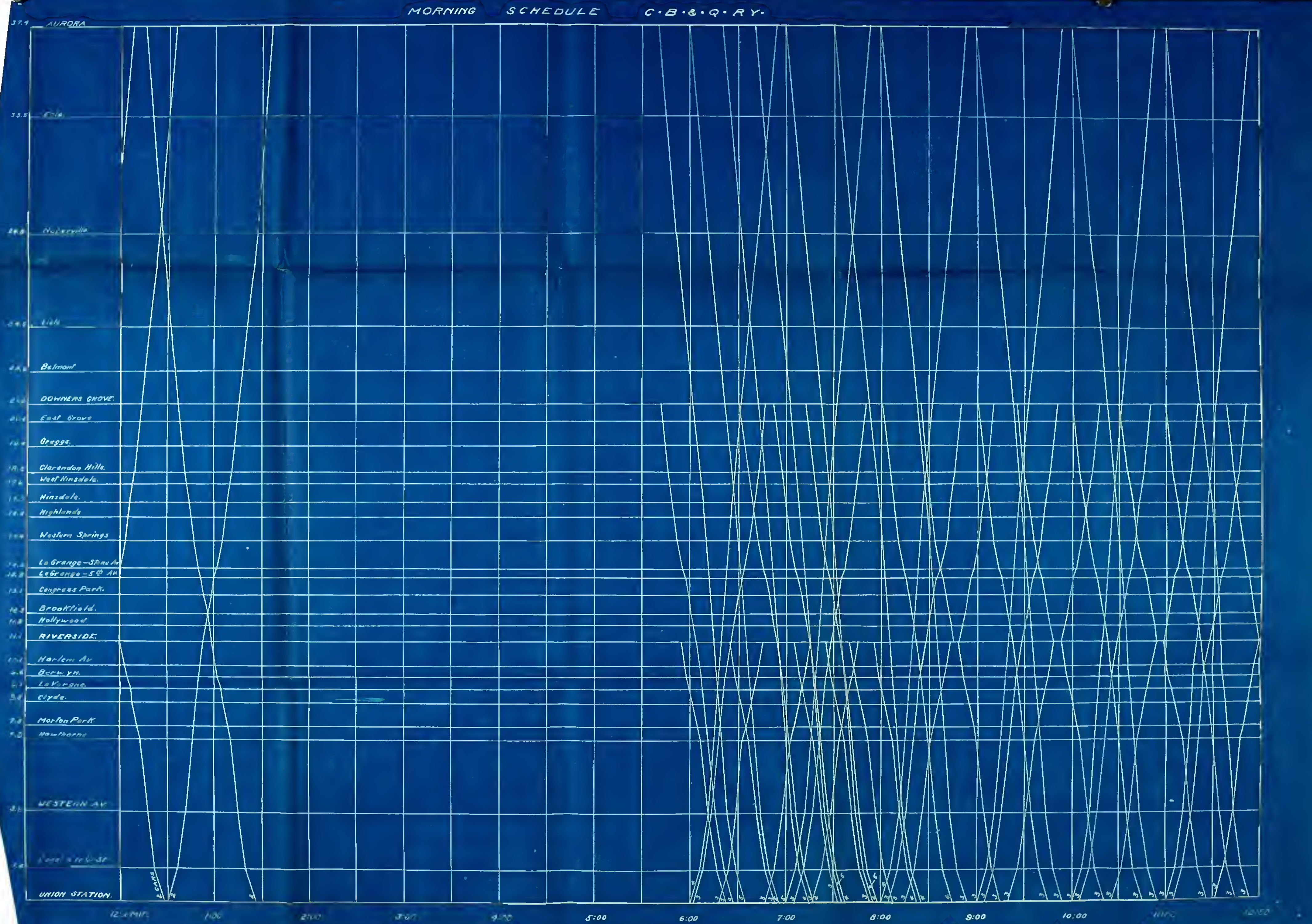

MORNING SCHEDULE C·B·&·Q·RY·
37.4 AURORA
33.5 Eola
Naperville
Lisle
Belmont
DOWNERS GROVE.
East Grove
Greggs.
Clarendon Hills.
West Hinsdale.
Hinsdale.
Highlands
Western Springs
La Grange–Stone Av
LaGrange–5th Av
Congress Park.
Brookfield.
Hollywood.
RIVERSIDE.
Harlem Av
Berwyn.
LaVergne.
Clyde.
Morton Park.
Hawthorne
WESTERN AV.
Canal & 16th St.
UNION STATION.
2 CARS
12 MID.
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00

FIG. 5

2
7
8
9
10
11

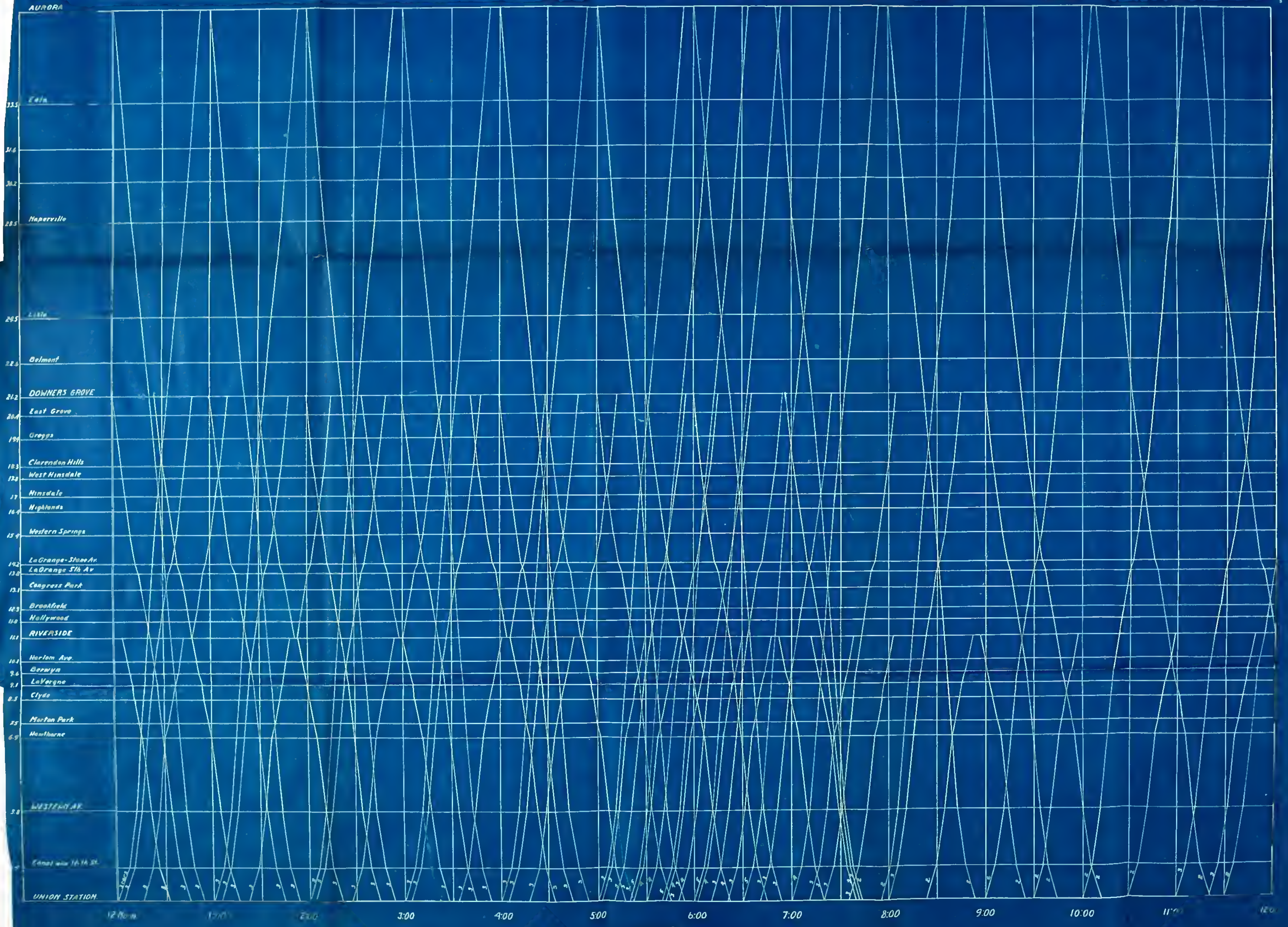

AFTERNOON SCHEDULE C.B. & Q. RY.

FIG. 6

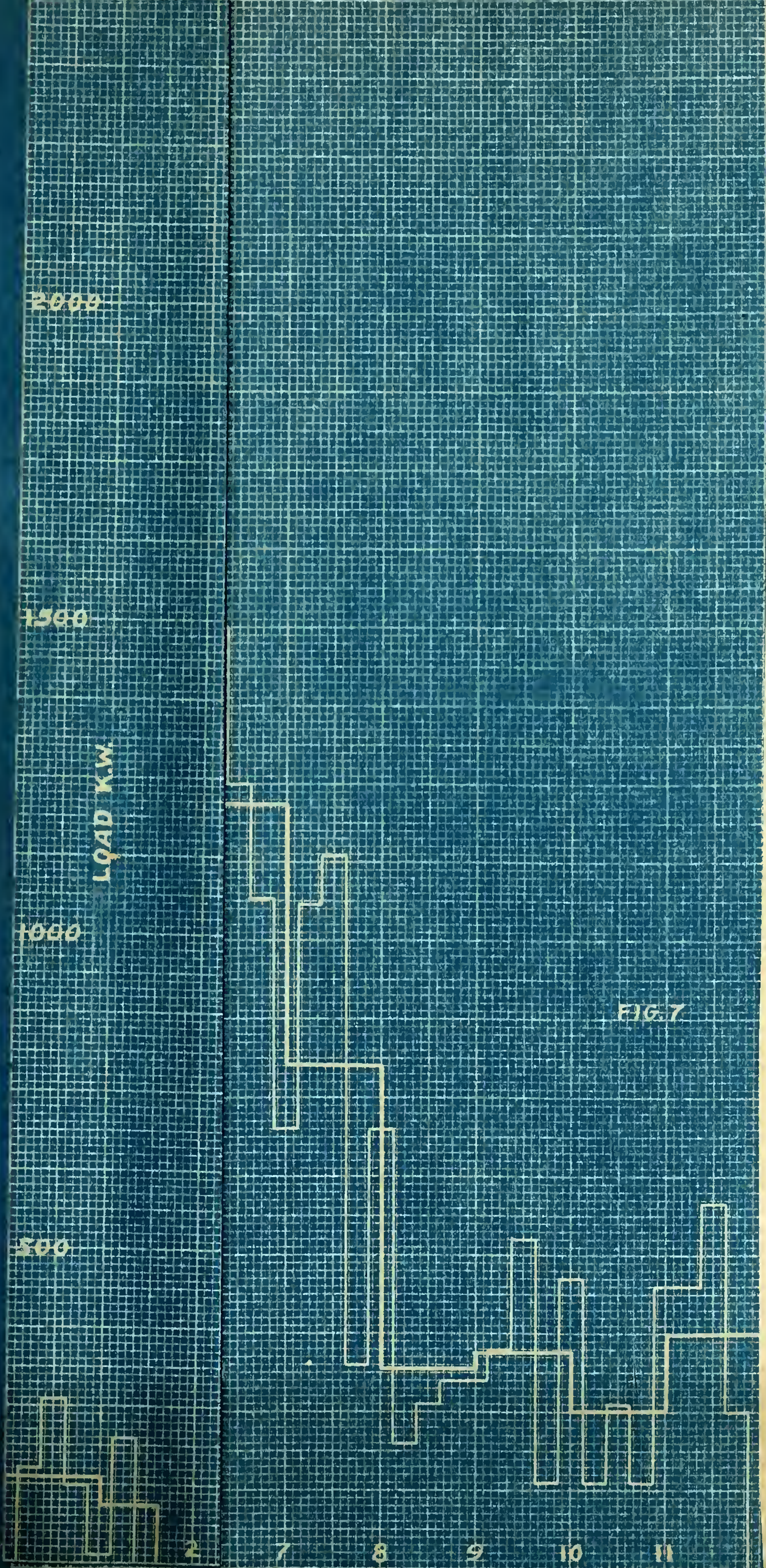
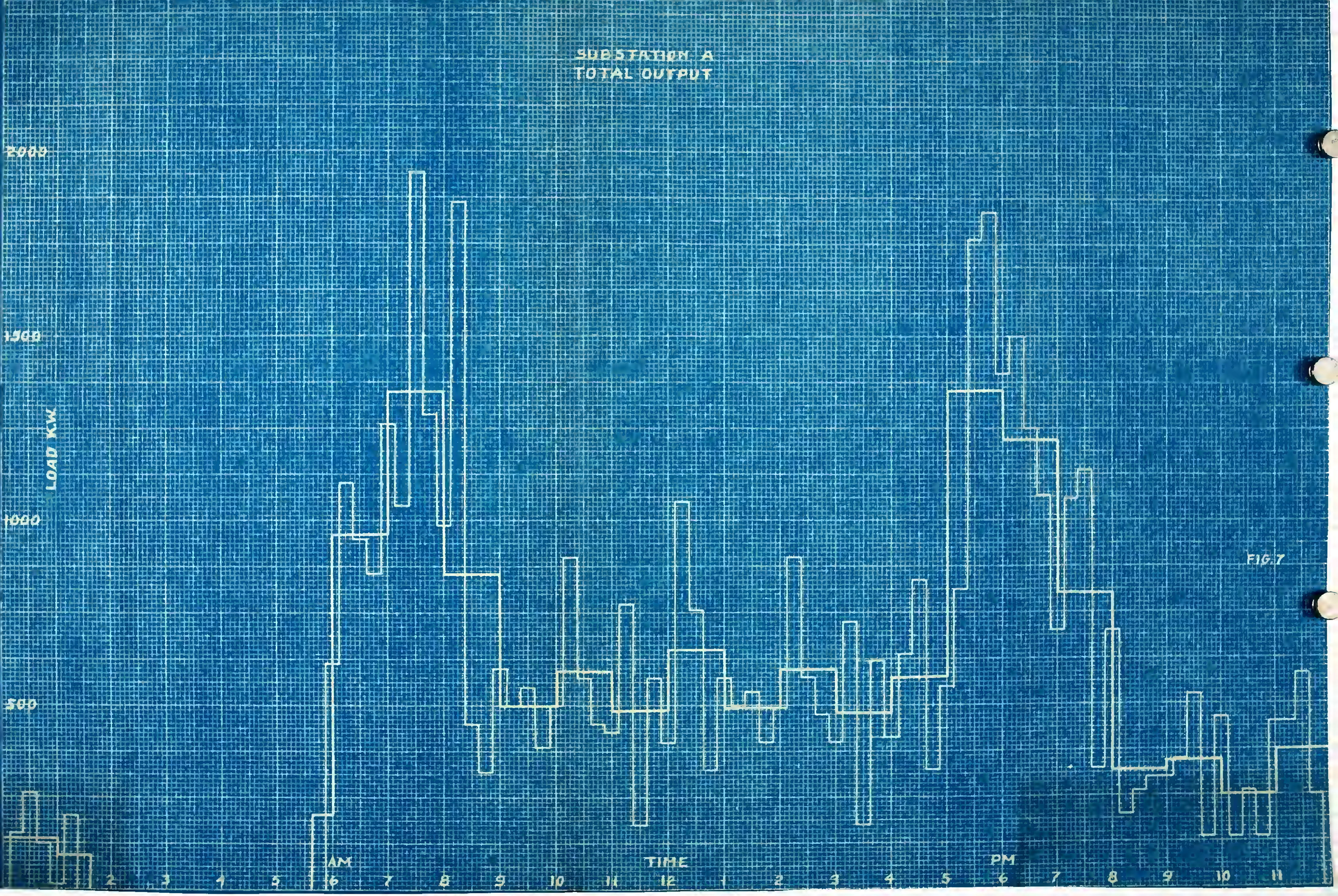


FIG. 7



SUBSTATION A
TOTAL OUTPUT

FIG. 7

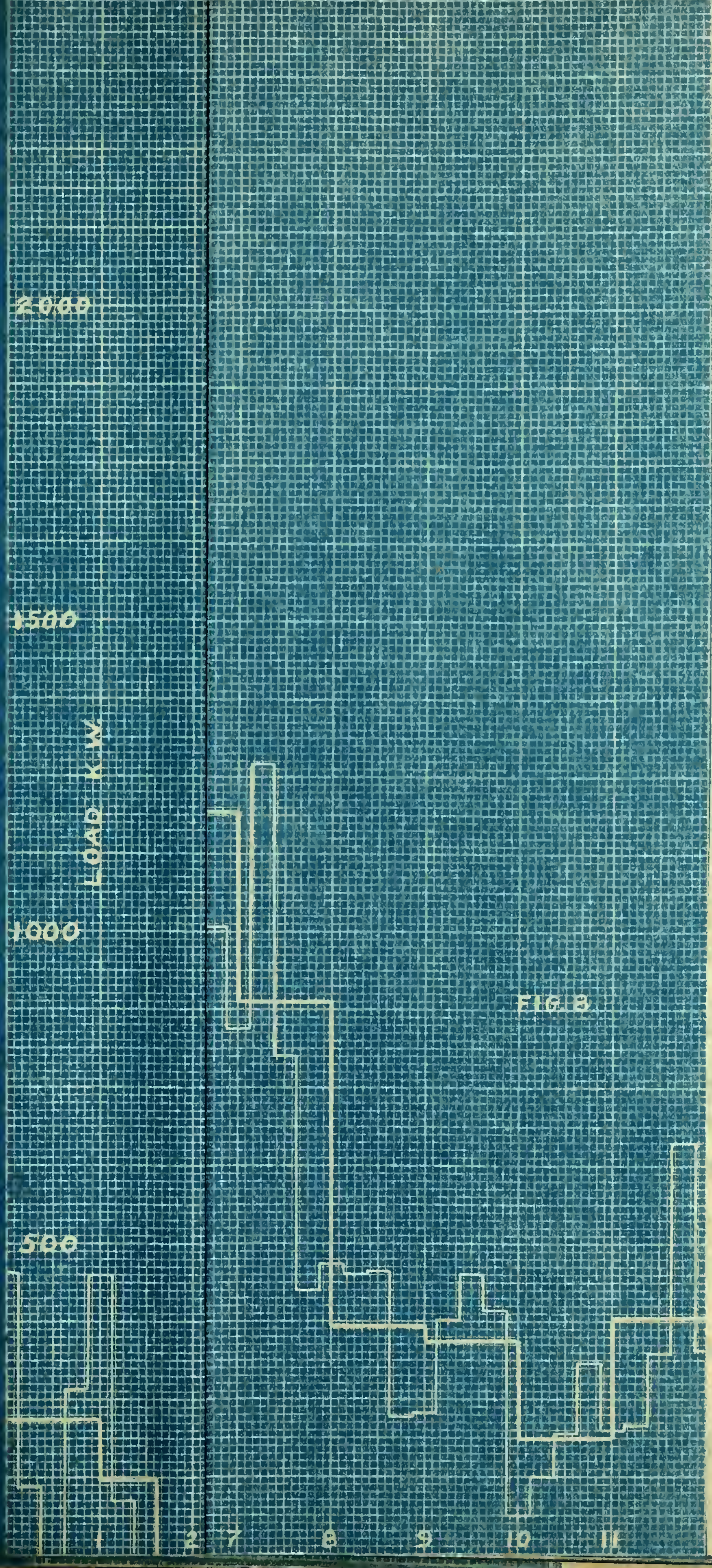


FIG. B

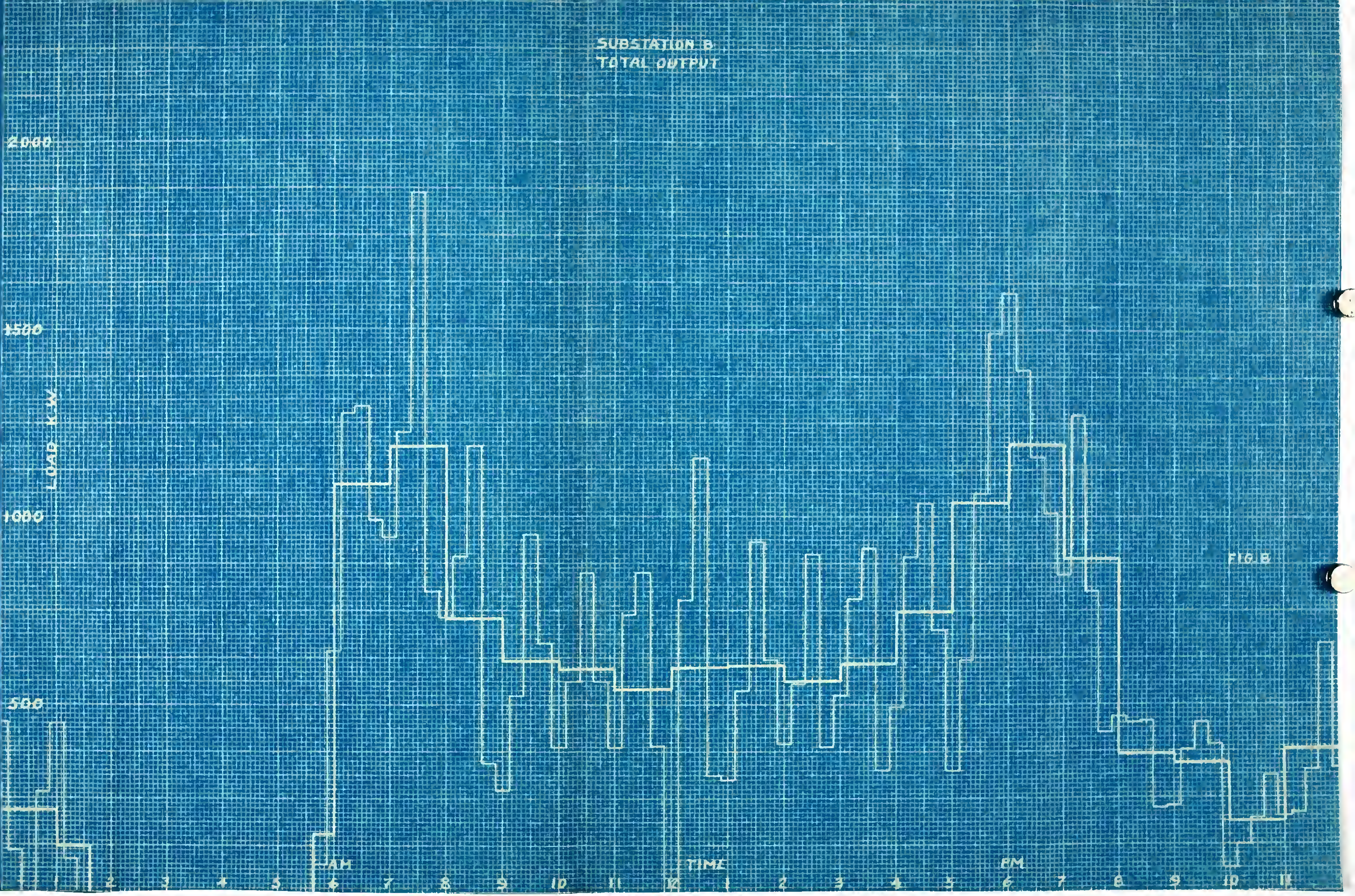

SUBSTATION B
TOTAL OUTPUT
LOAD K.W.
2000
1500
1000
500
AM
TIME
PM
1
2
3
4
5
6
7
8
9
10
11
12
1
2
3
4
5
6
7
8
9
10
11

FIG. 8

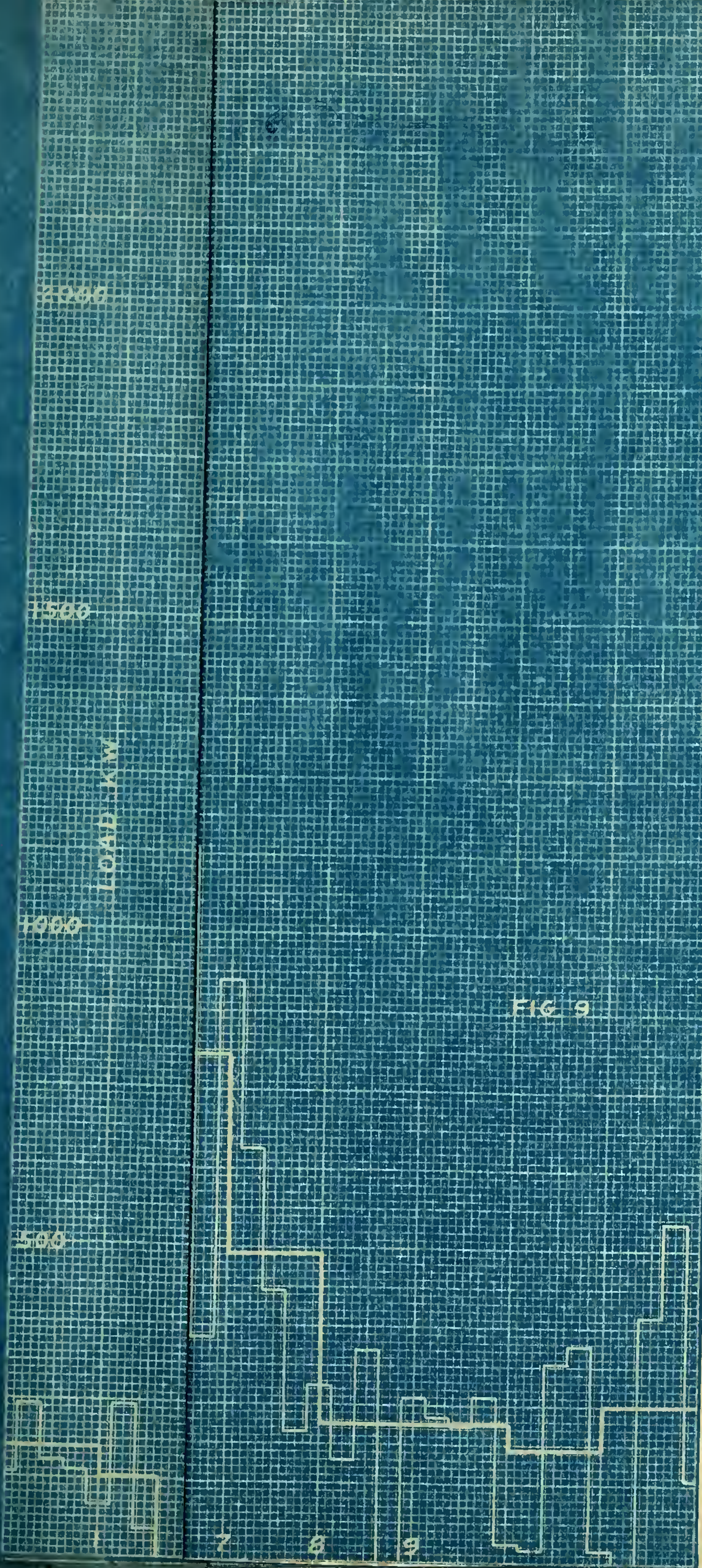


FIG 9

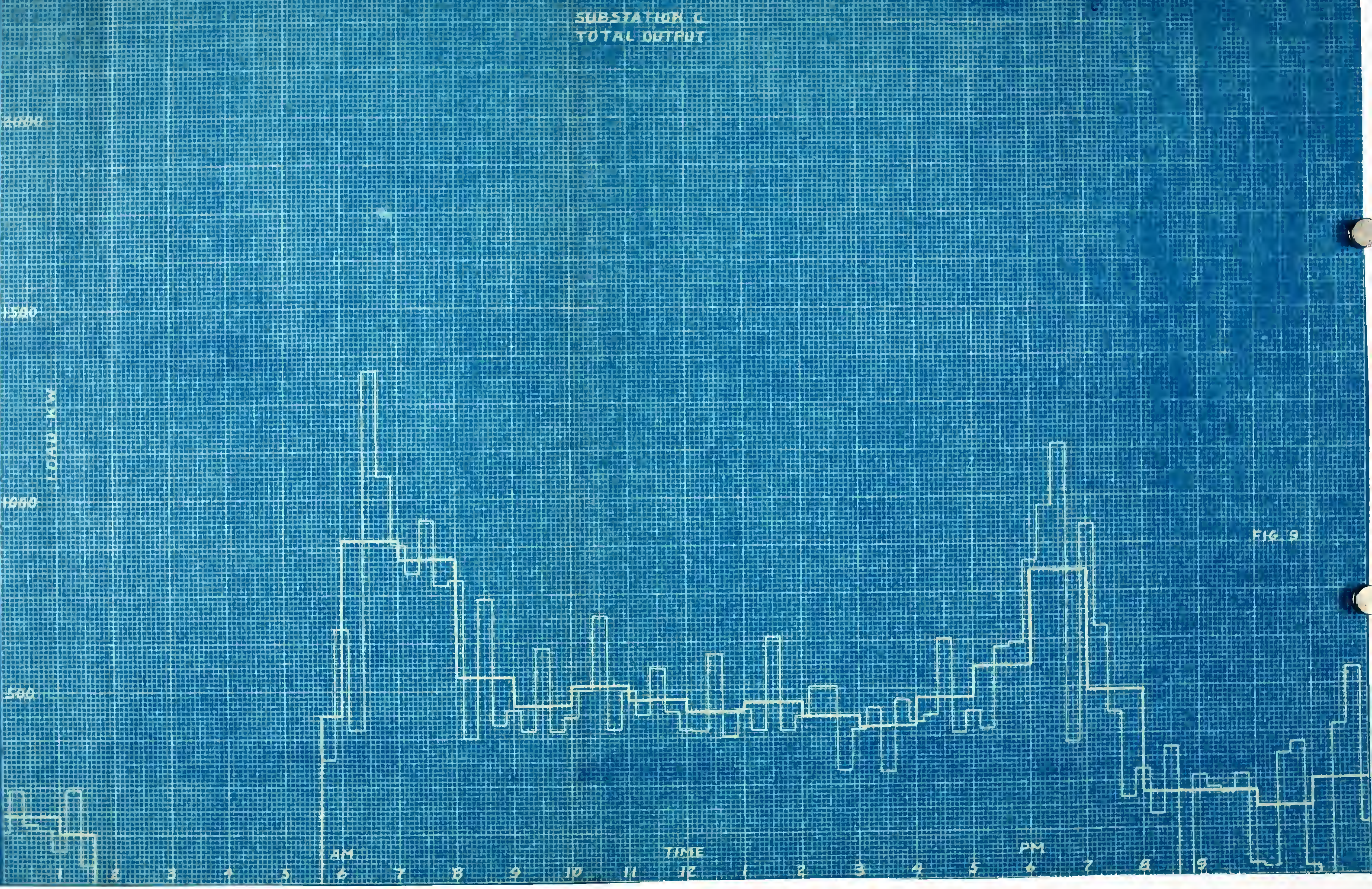
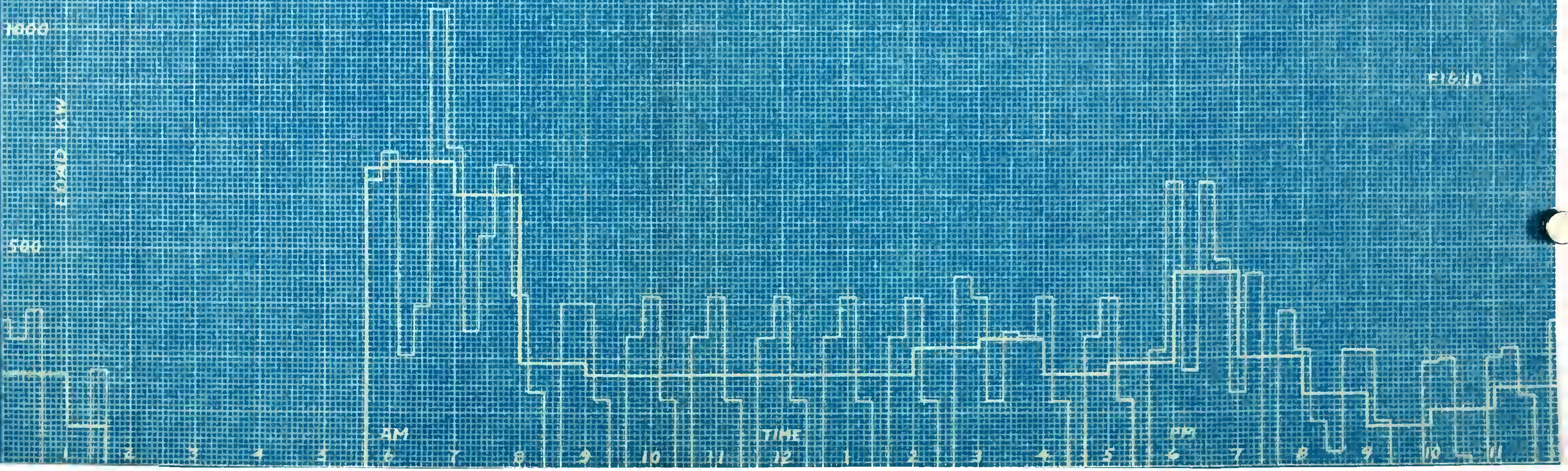

SUBSTATION C
TOTAL OUTPUT
2000
1500
1000
500
LOAD K.W.
AM
TIME
PM
1
2
3
4
5
6
7
8
9
10
11
12
1
2
3
4
5
6
7
8
9
10

FIG. 9



SUBSTATION D
TOTAL OUTPUT

FIG.10

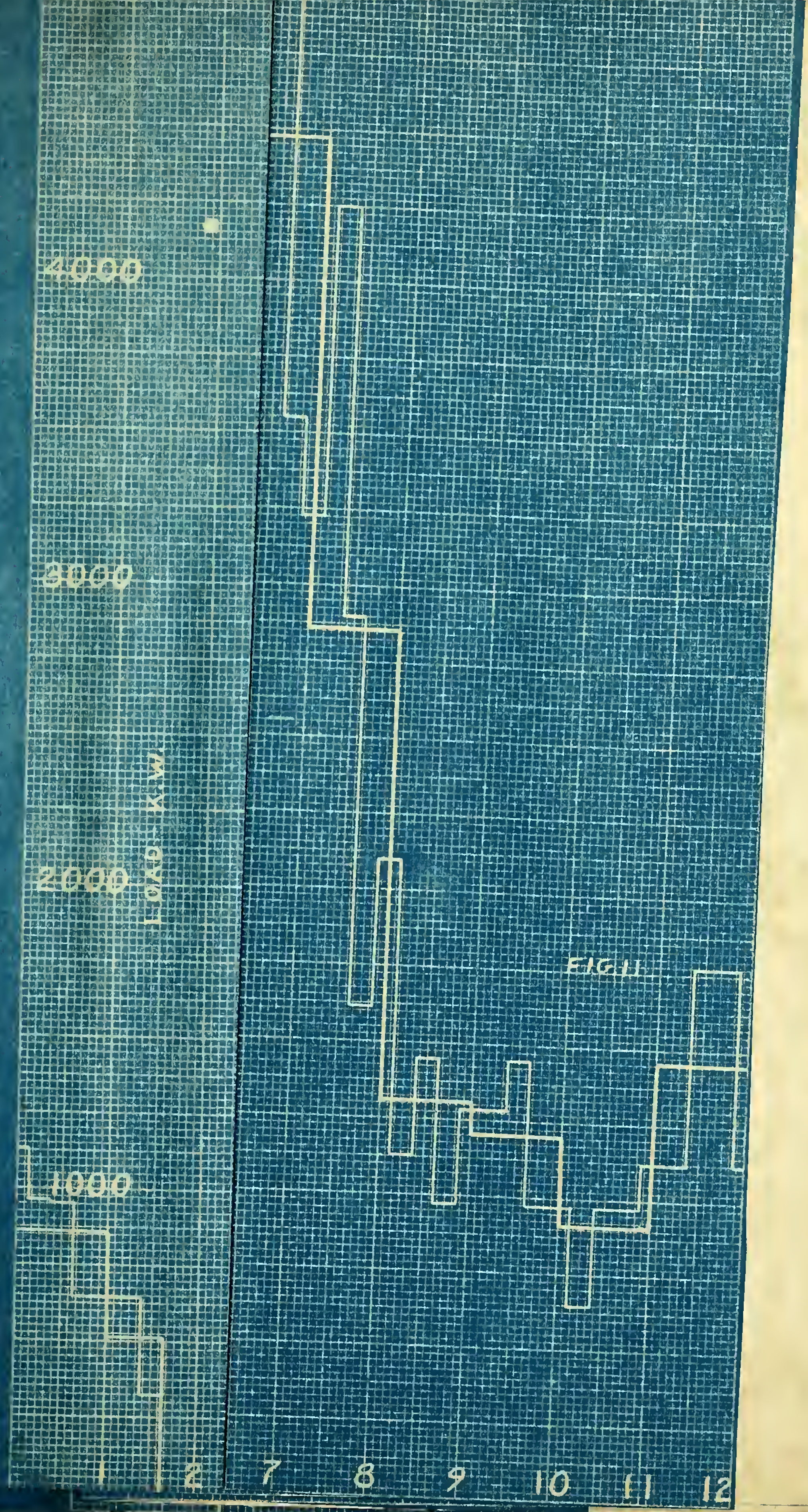
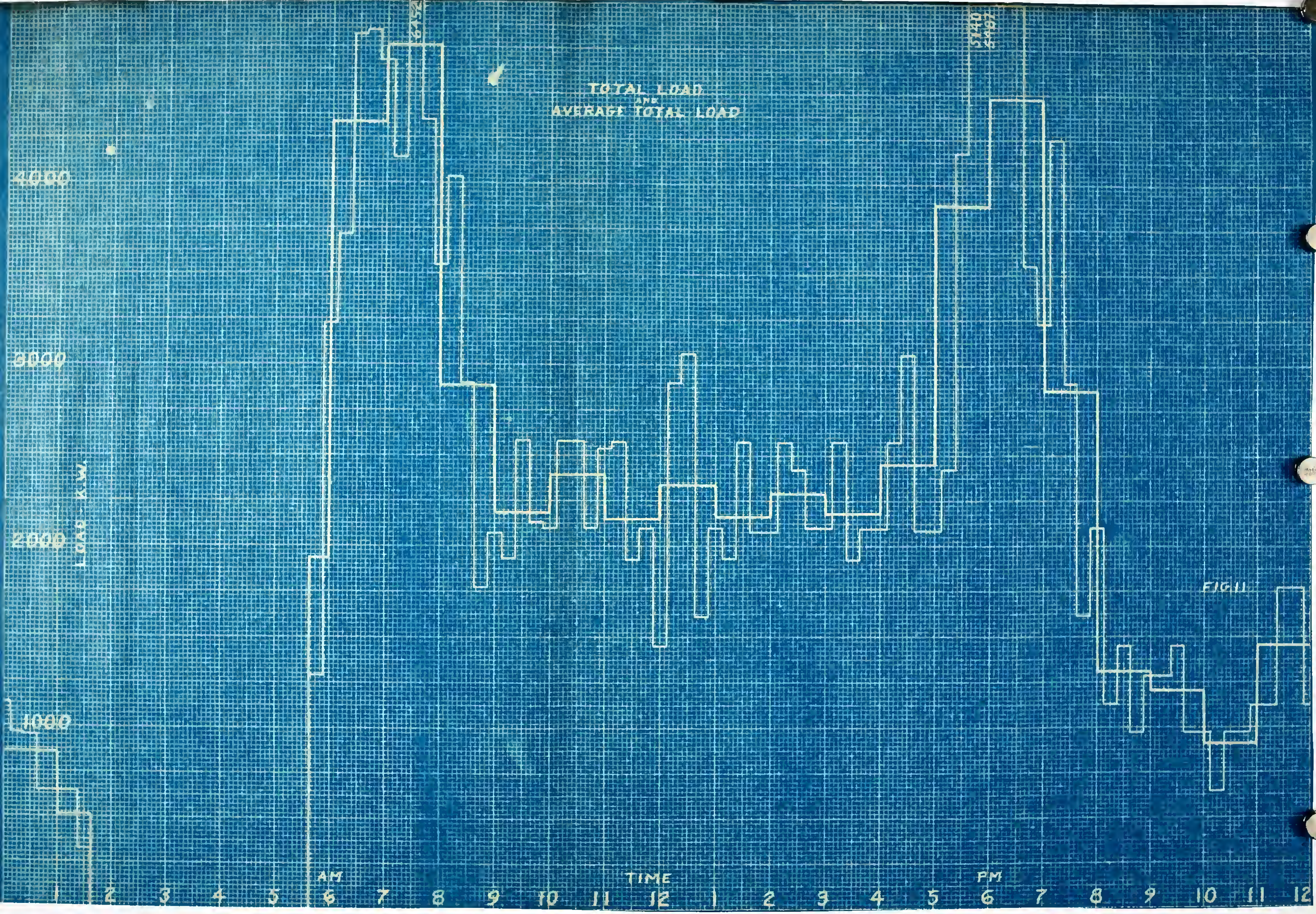


FIG. 11



TOTAL LOAD AND AVERAGE TOTAL LOAD

FIG. 11

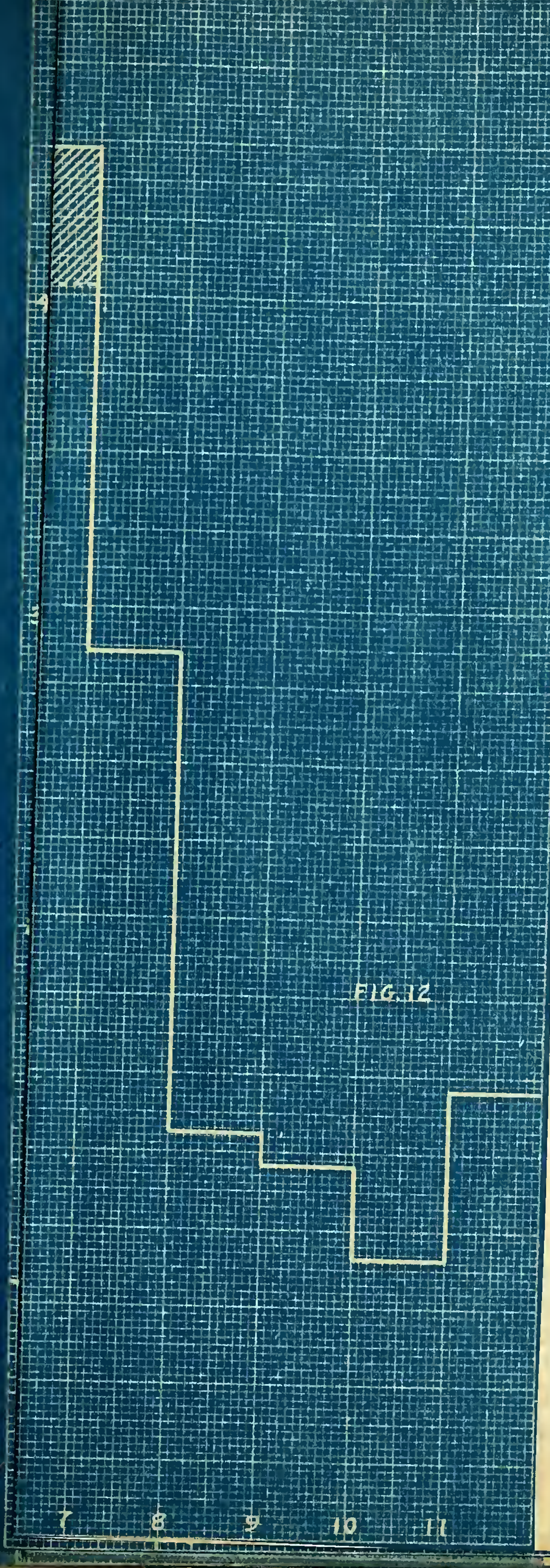
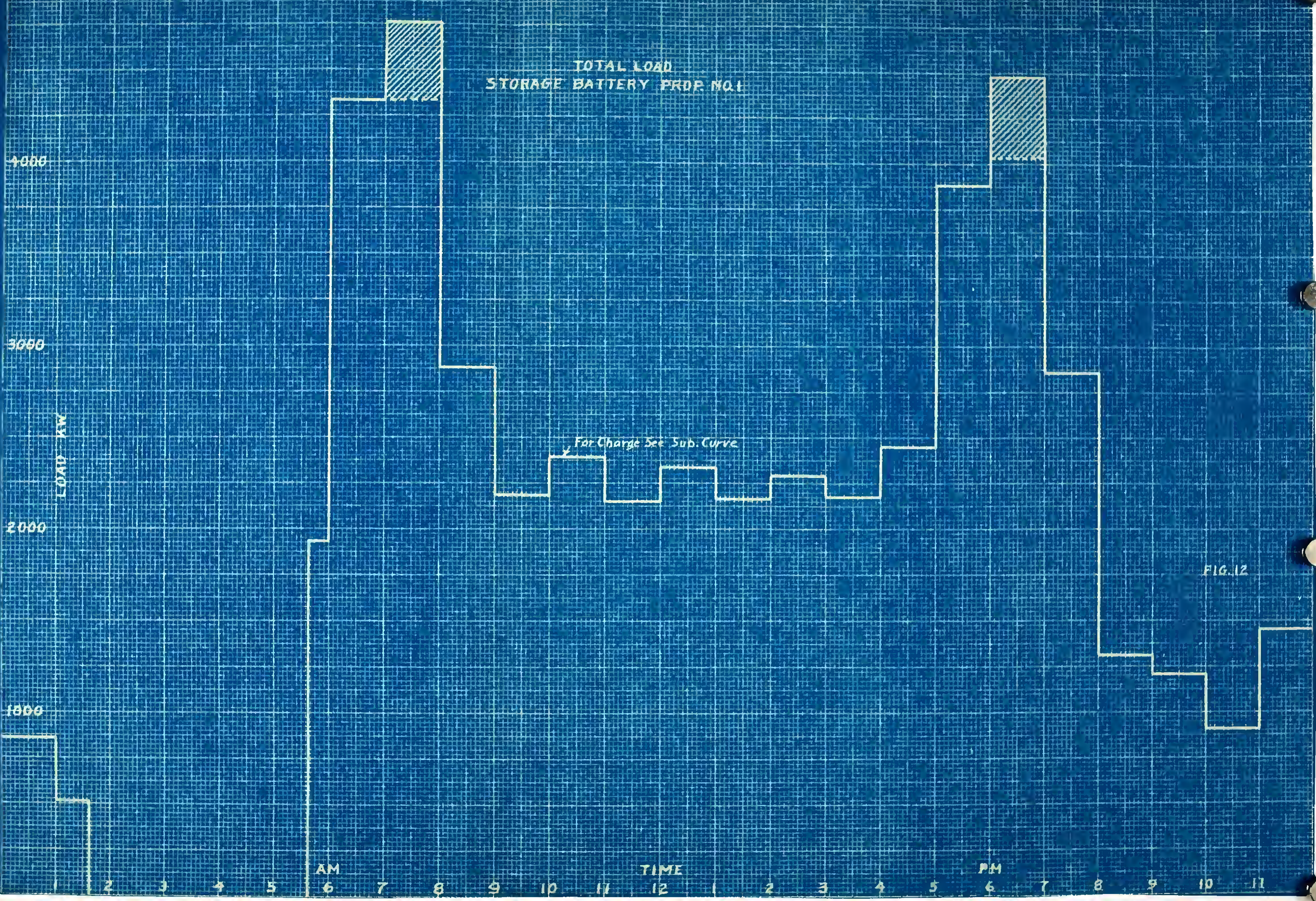


FIG. 12



TOTAL LOAD
STORAGE BATTERY PROP. NO.1

For Charge See Sub. Curve

FIG. 12

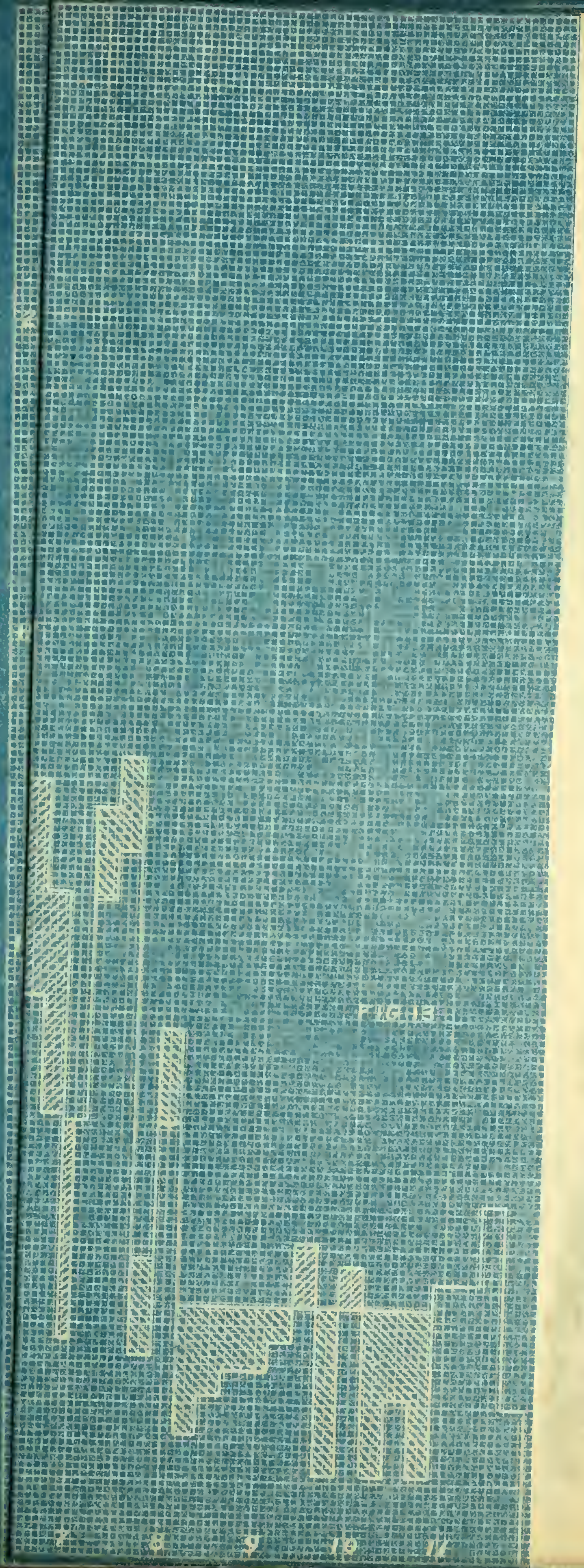


FIG. 13

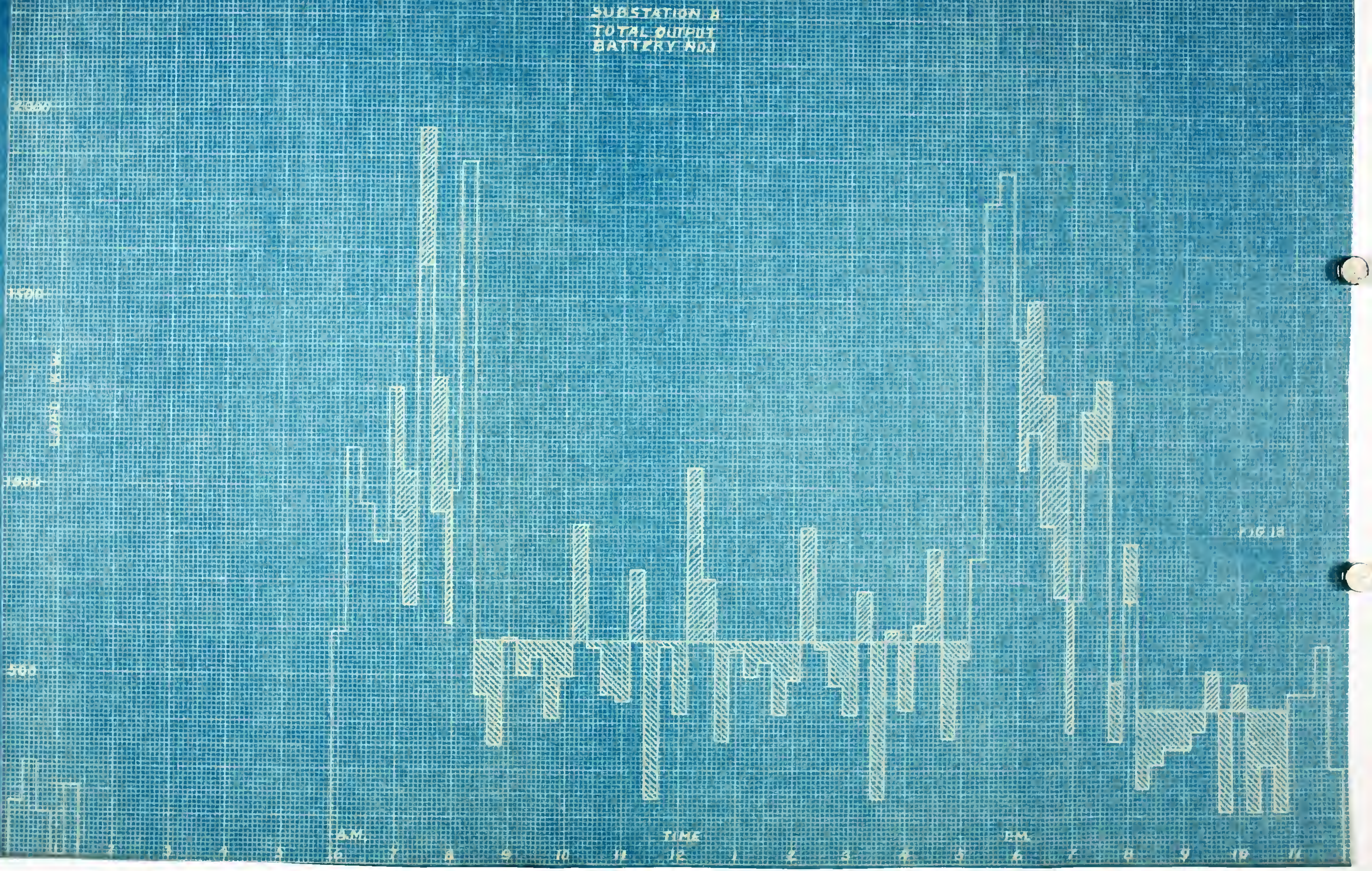

SUBSTATION A
TOTAL OUTPUT
BATTERY NO.1
2000
1500
1000
500
LOAD K.W.
A.M.
TIME
P.M.
1
2
3
4
5
6
7
8
9
10
11
12
1
2
3
4
5
6
7
8
9
10
11

FIG 18

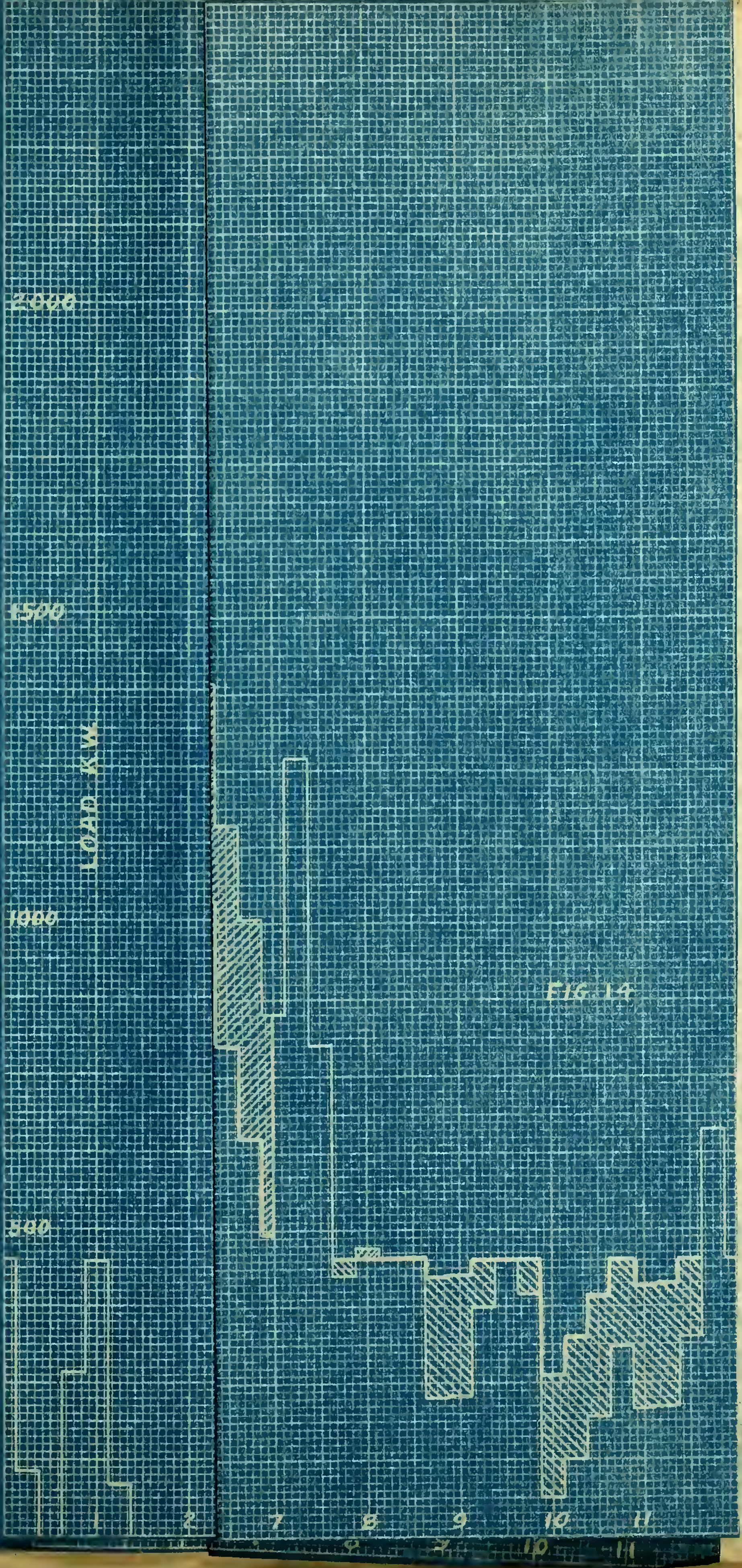


FIG. 14

SUBSTATION B
TOTAL OUTPUT
BATTERY NO.1

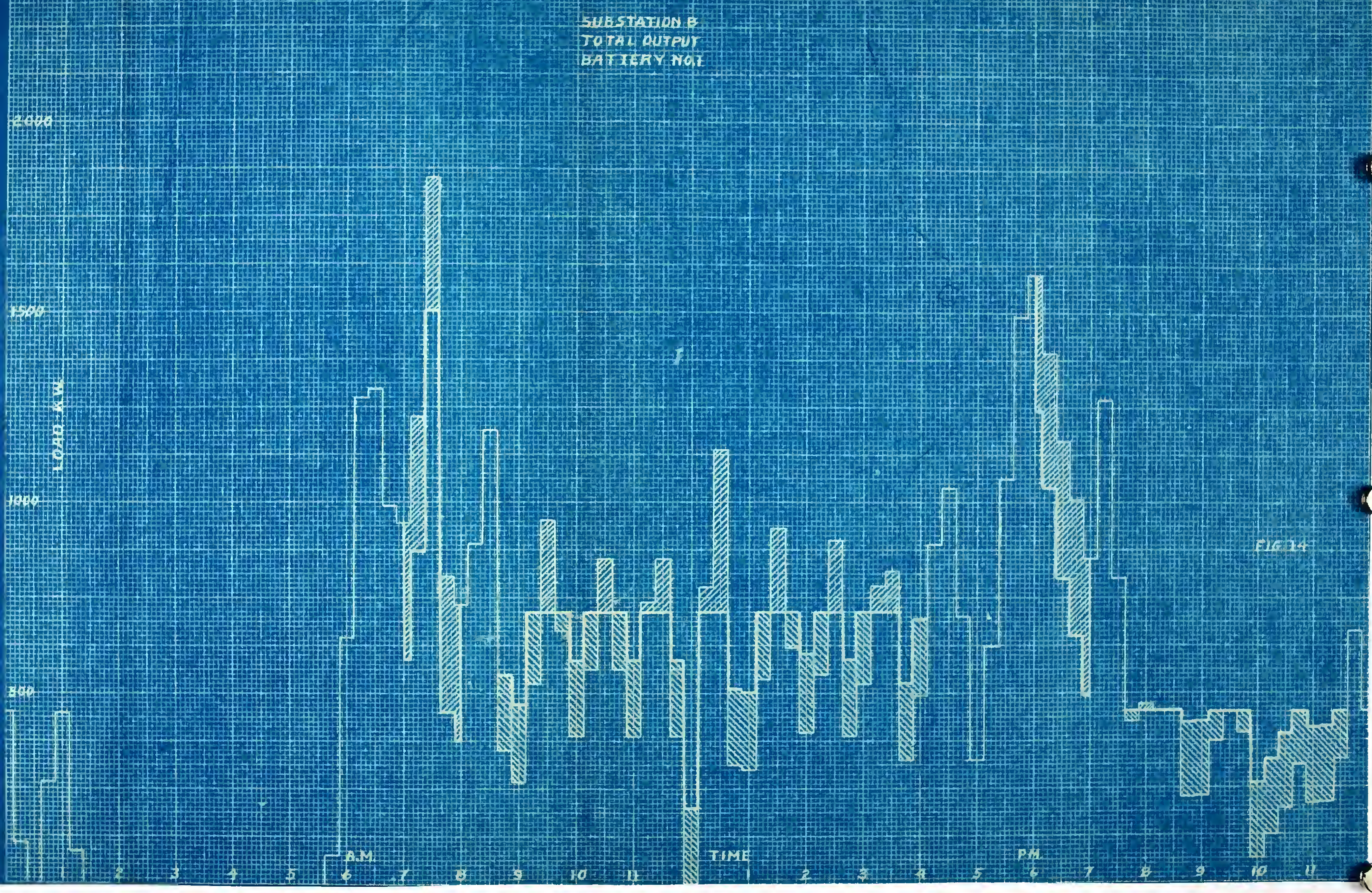


FIG. 14

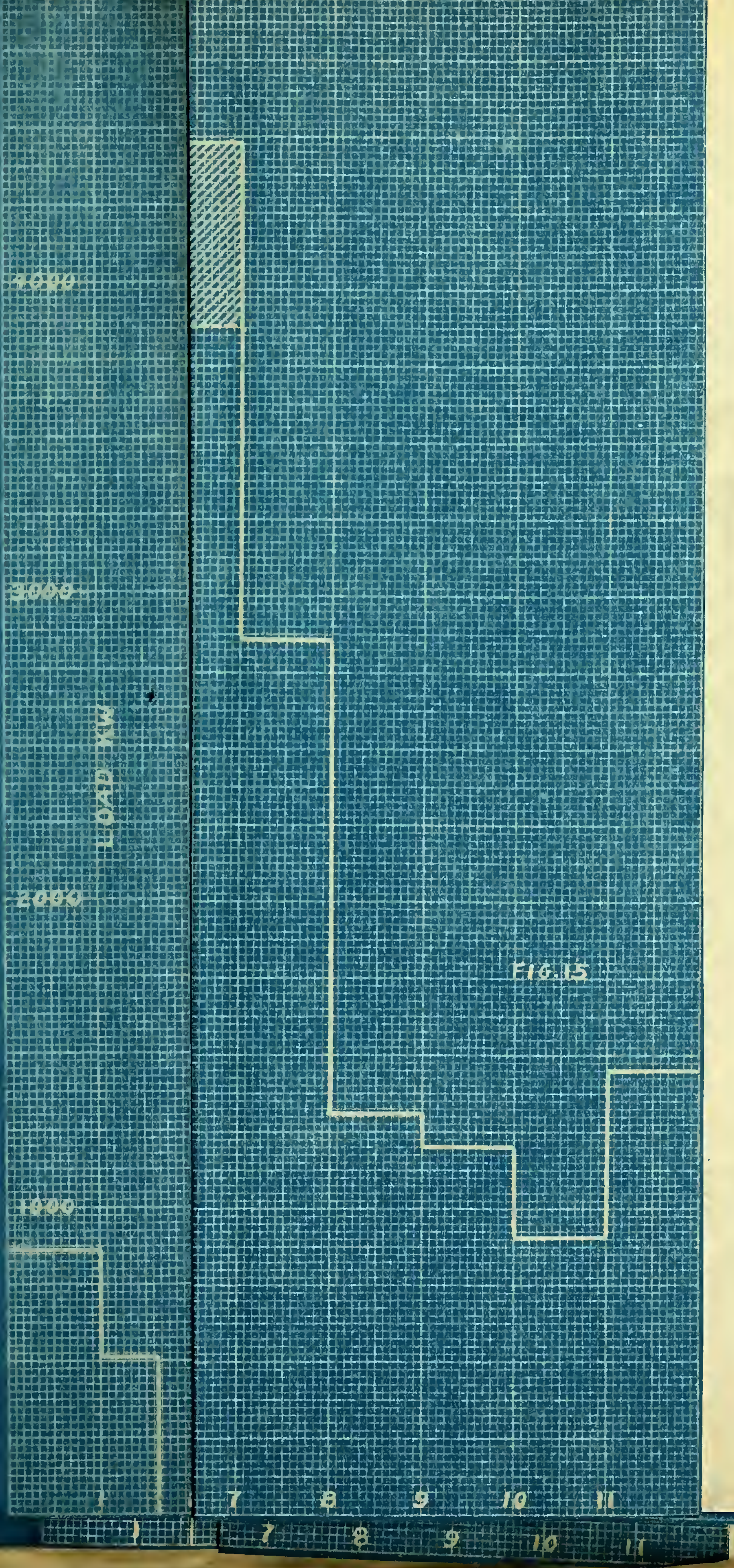
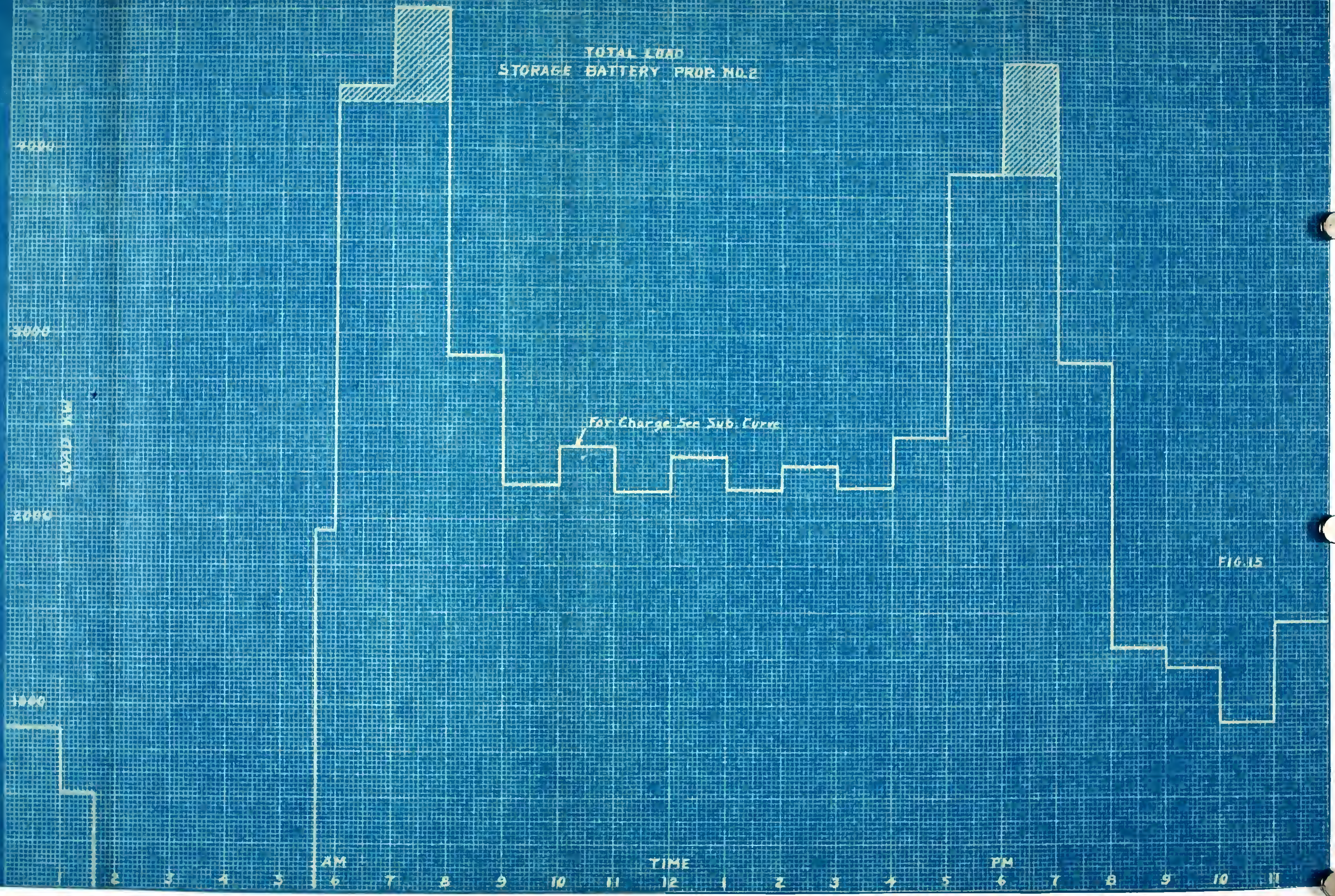


FIG. 15



TOTAL LOAD
STORAGE BATTERY PROP. NO. 2

For Charge See Sub. Curve

FIG. 15

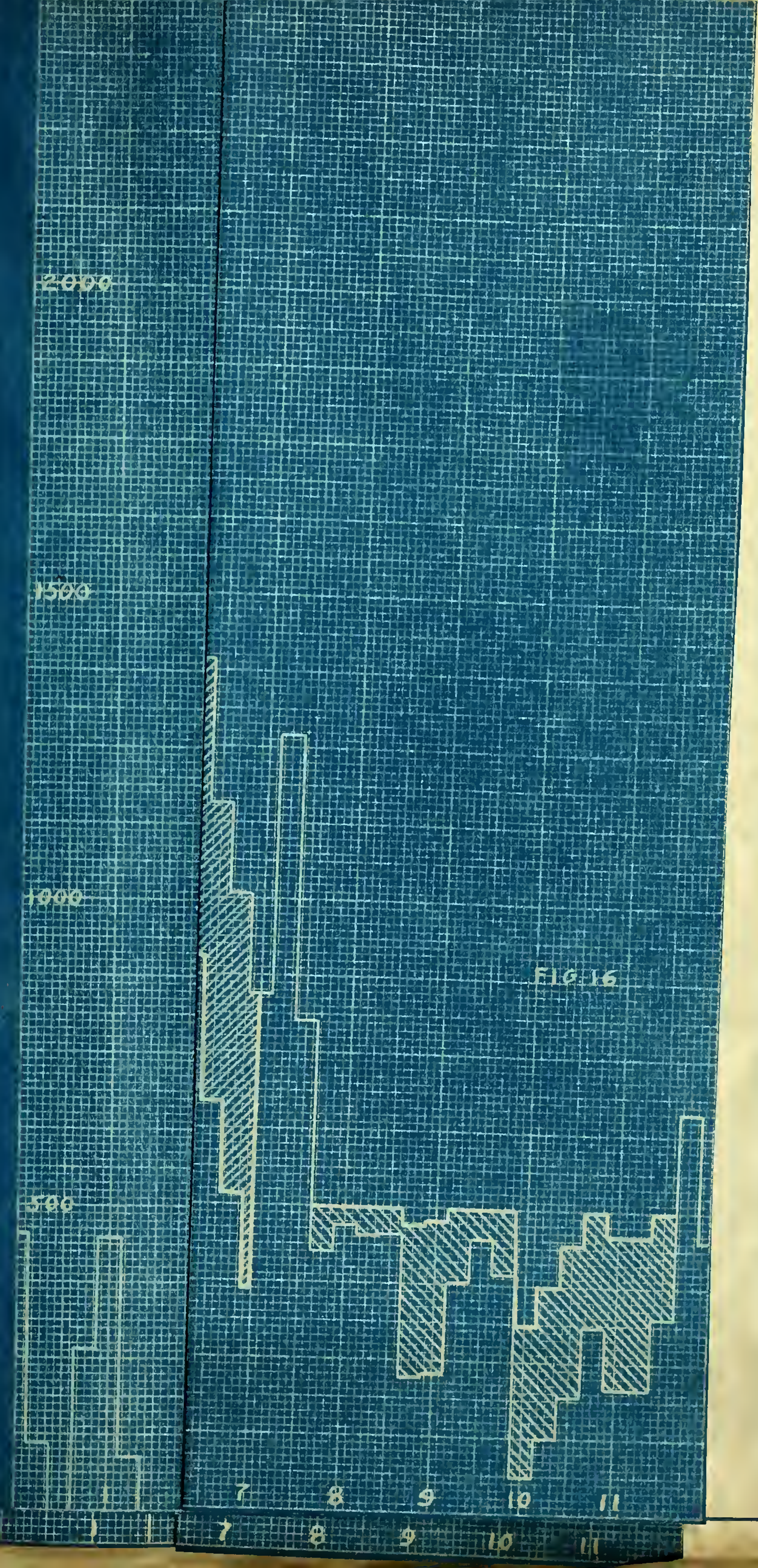


FIG. 16

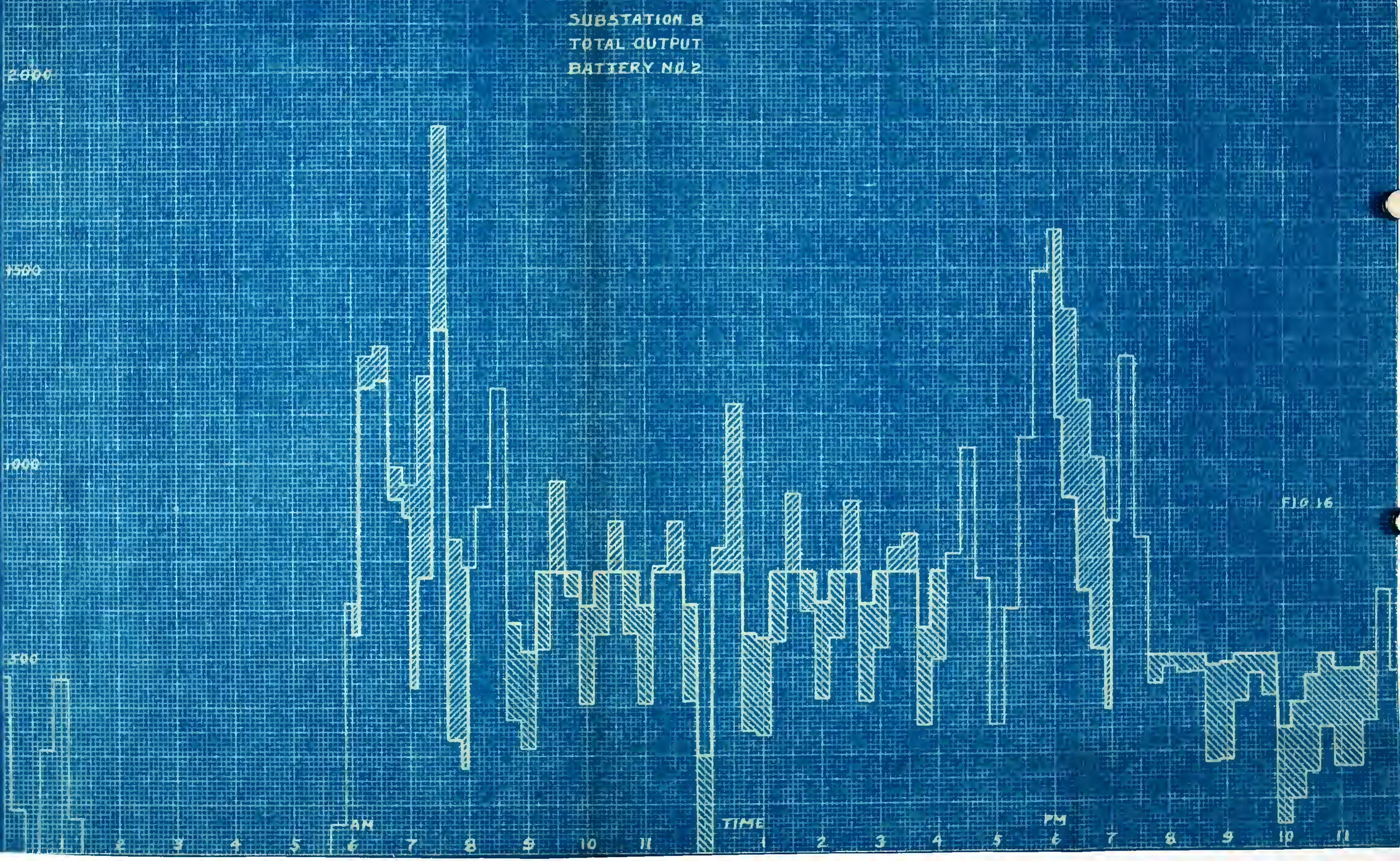

SUBSTATION B
TOTAL OUTPUT
BATTERY NO. 2
2000
1500
1000
500
1
2
3
4
5
AM
6
7
8
9
10
11
TIME
1
2
3
4
5
PM
6
7
8
9
10
11

FIG. 16

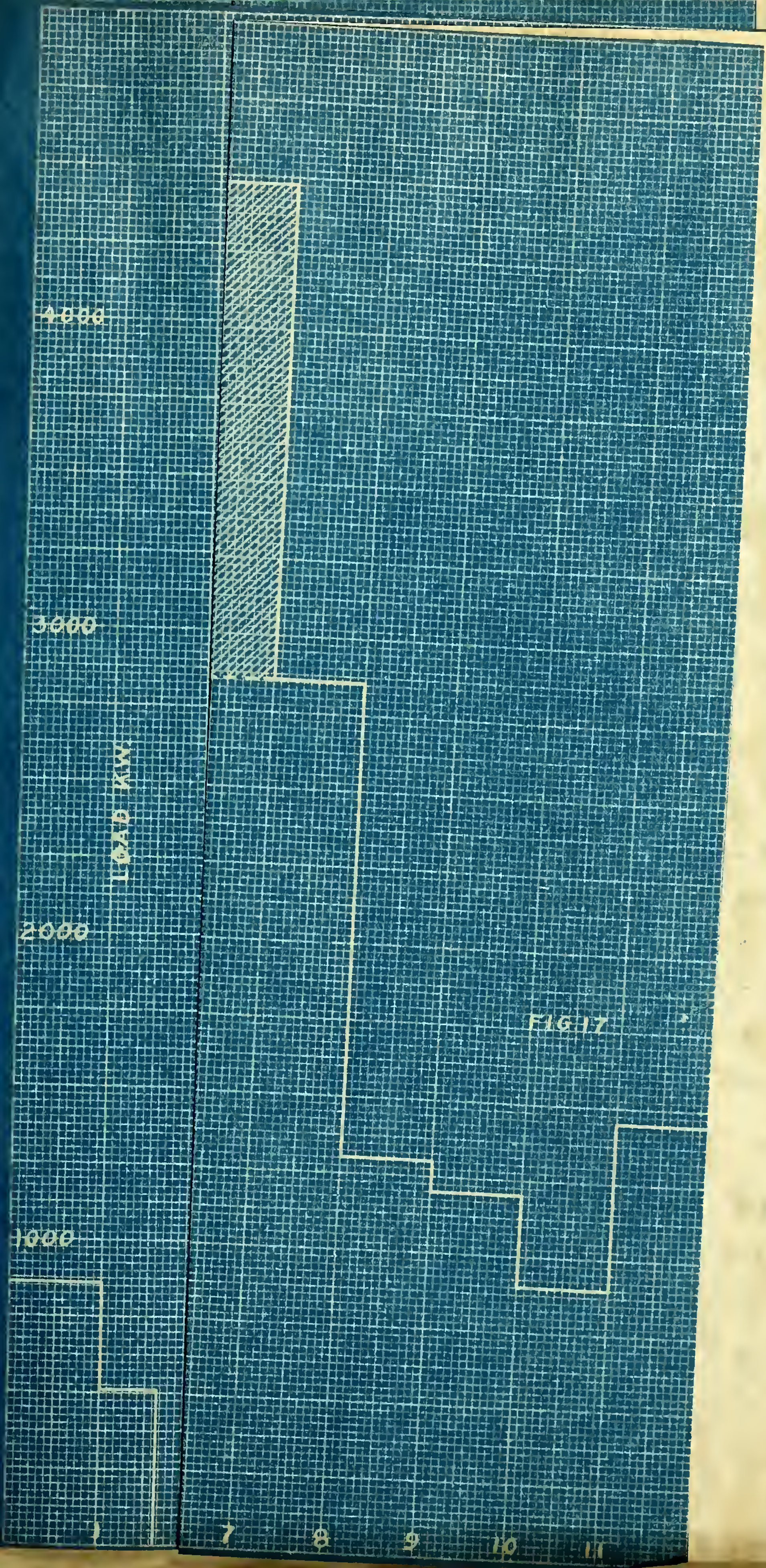
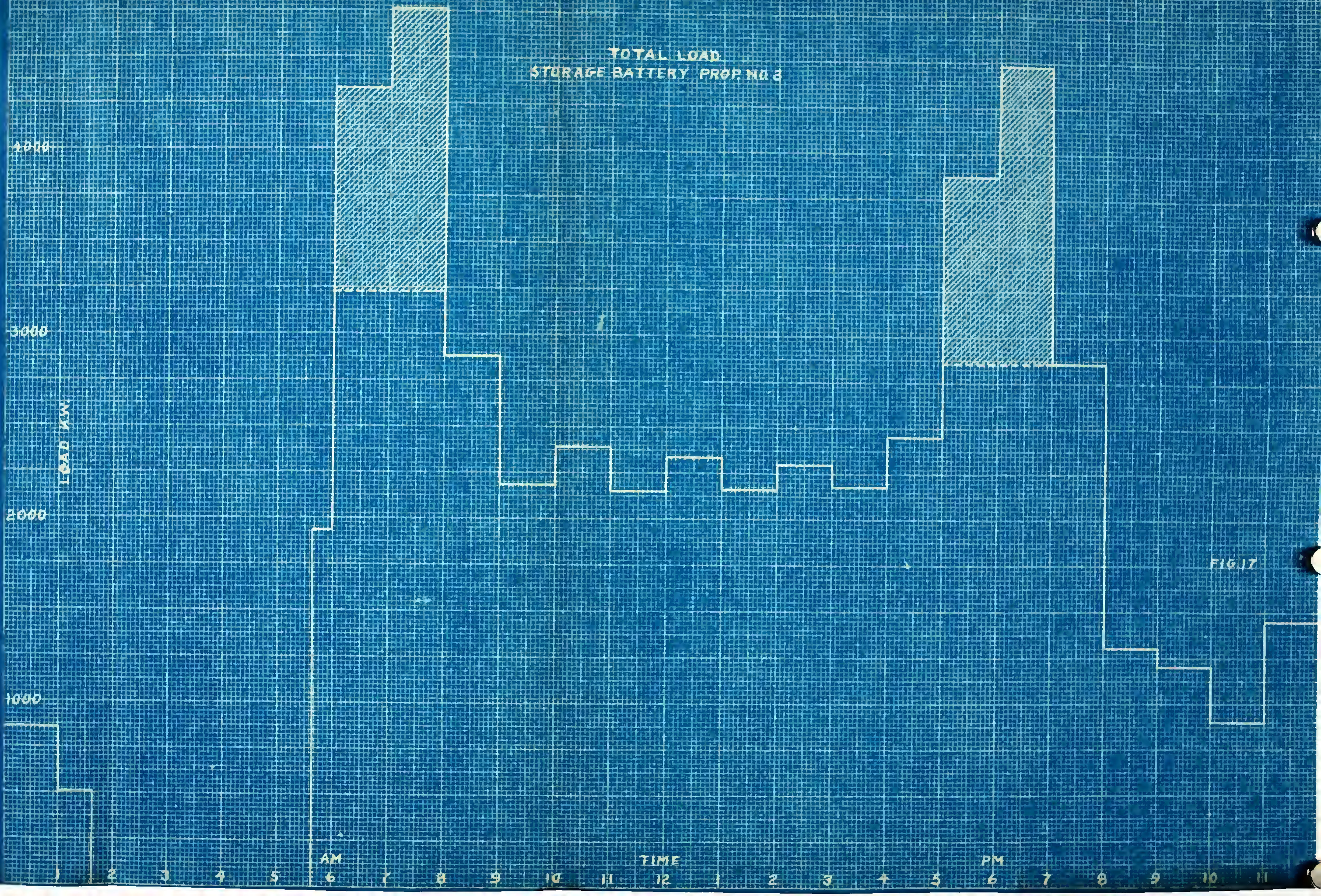


FIG 17



TOTAL LOAD
STORAGE BATTERY PROP. NO 3

FIG. 17

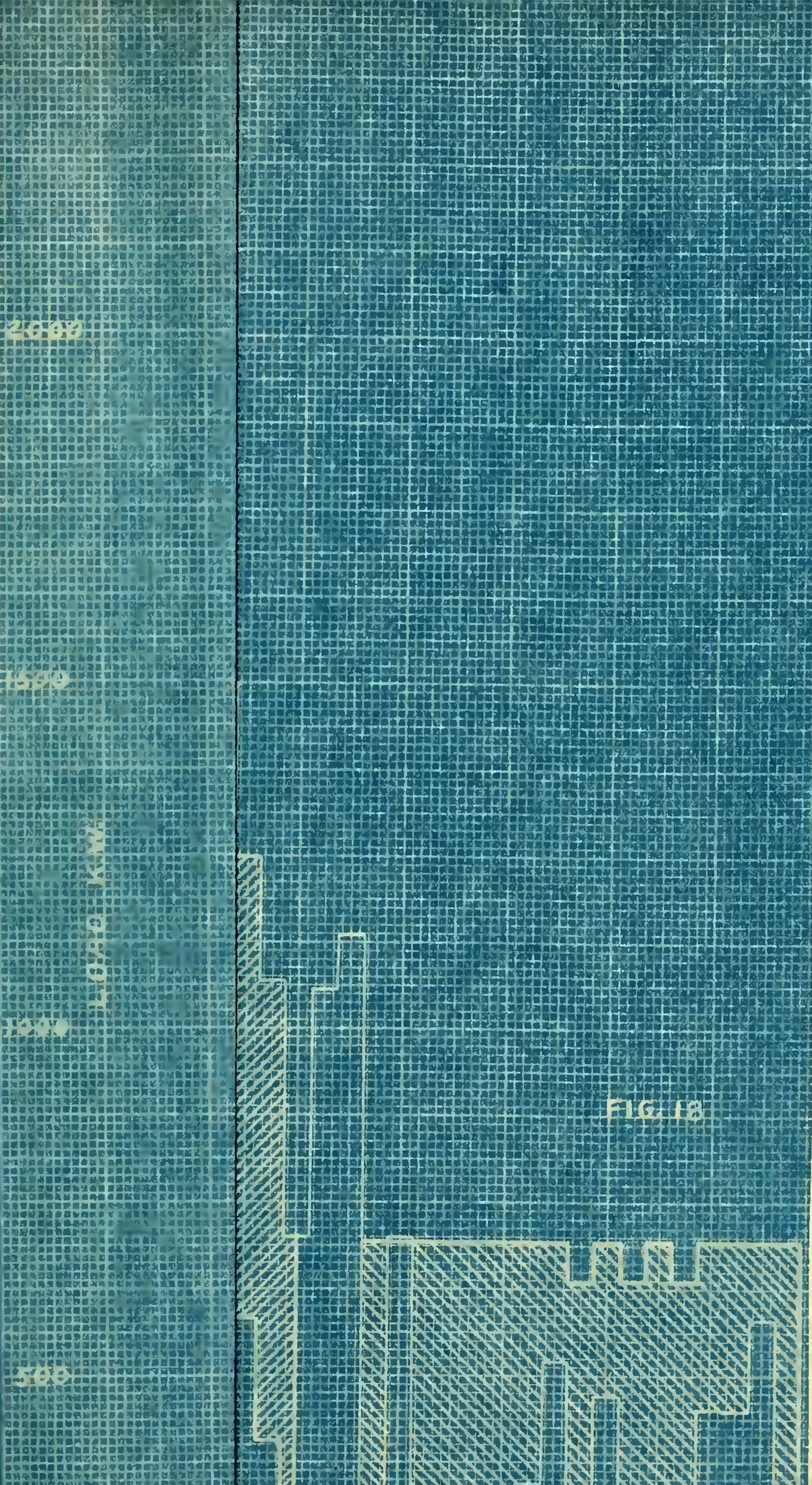
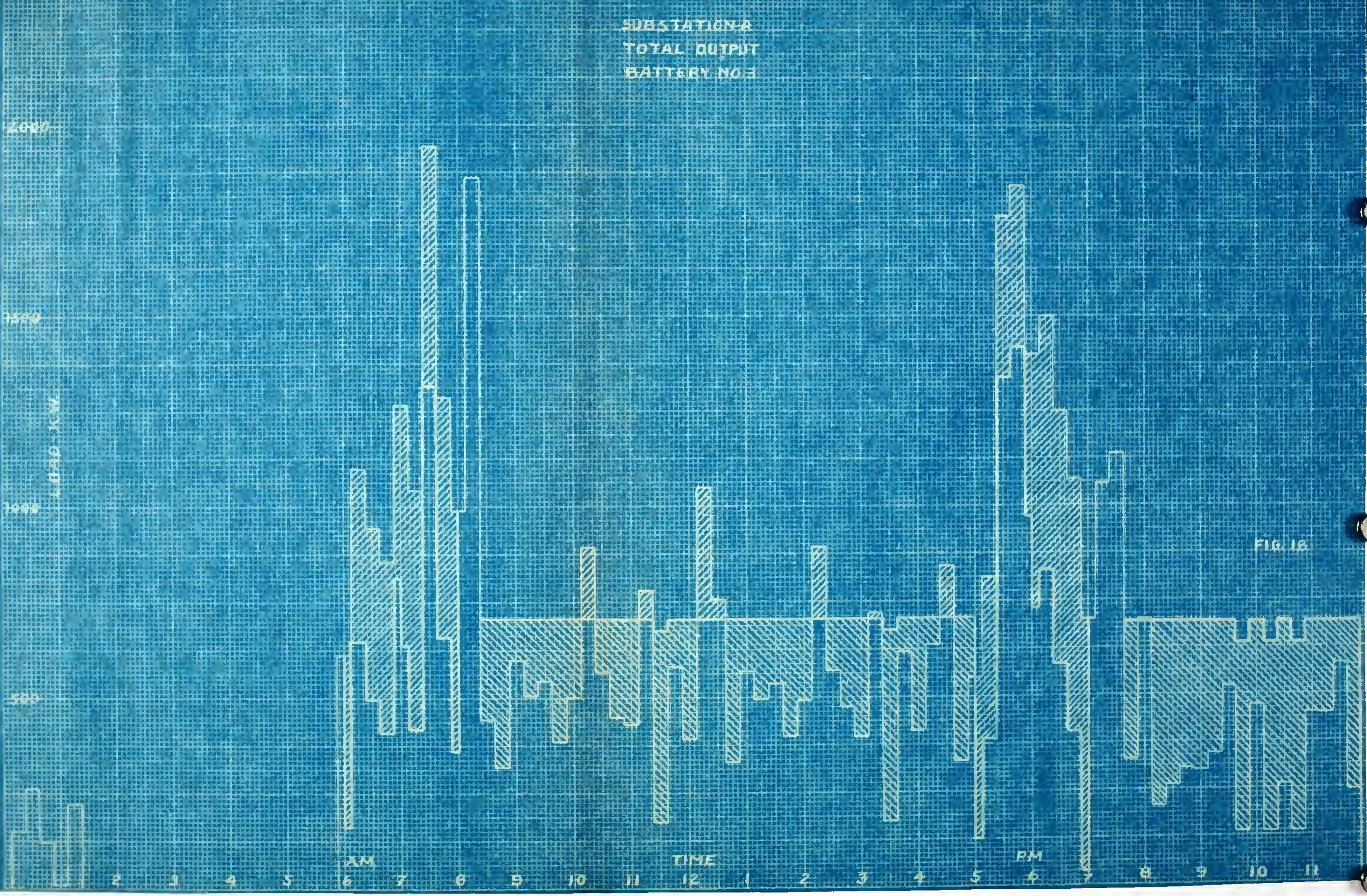


FIG. 18



SUBSTATION A
TOTAL OUTPUT
BATTERY NO. 3

FIG. 18

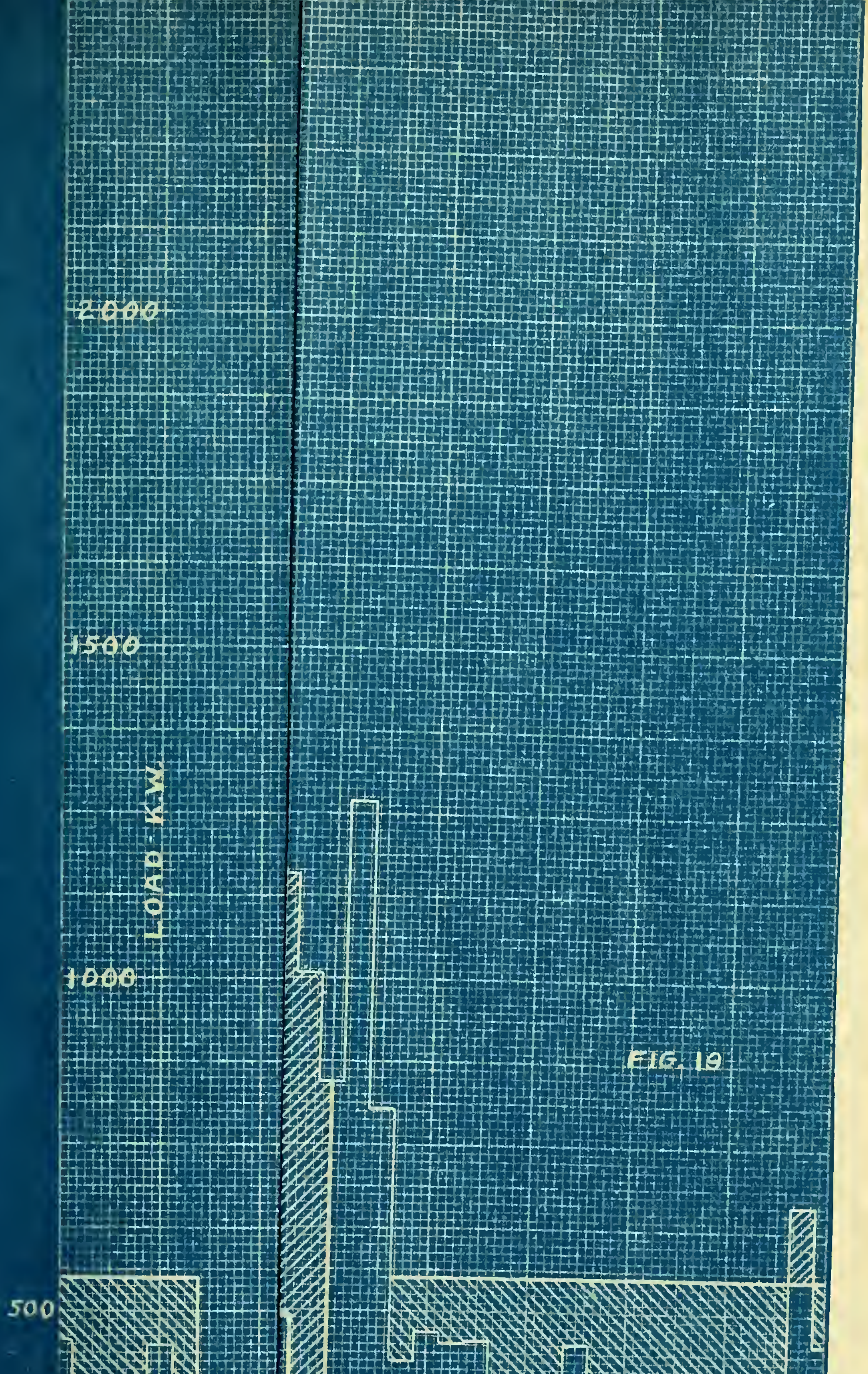


FIG. 19

SUBSTATION B
TOTAL OUTPUT
BATTERY NO.3

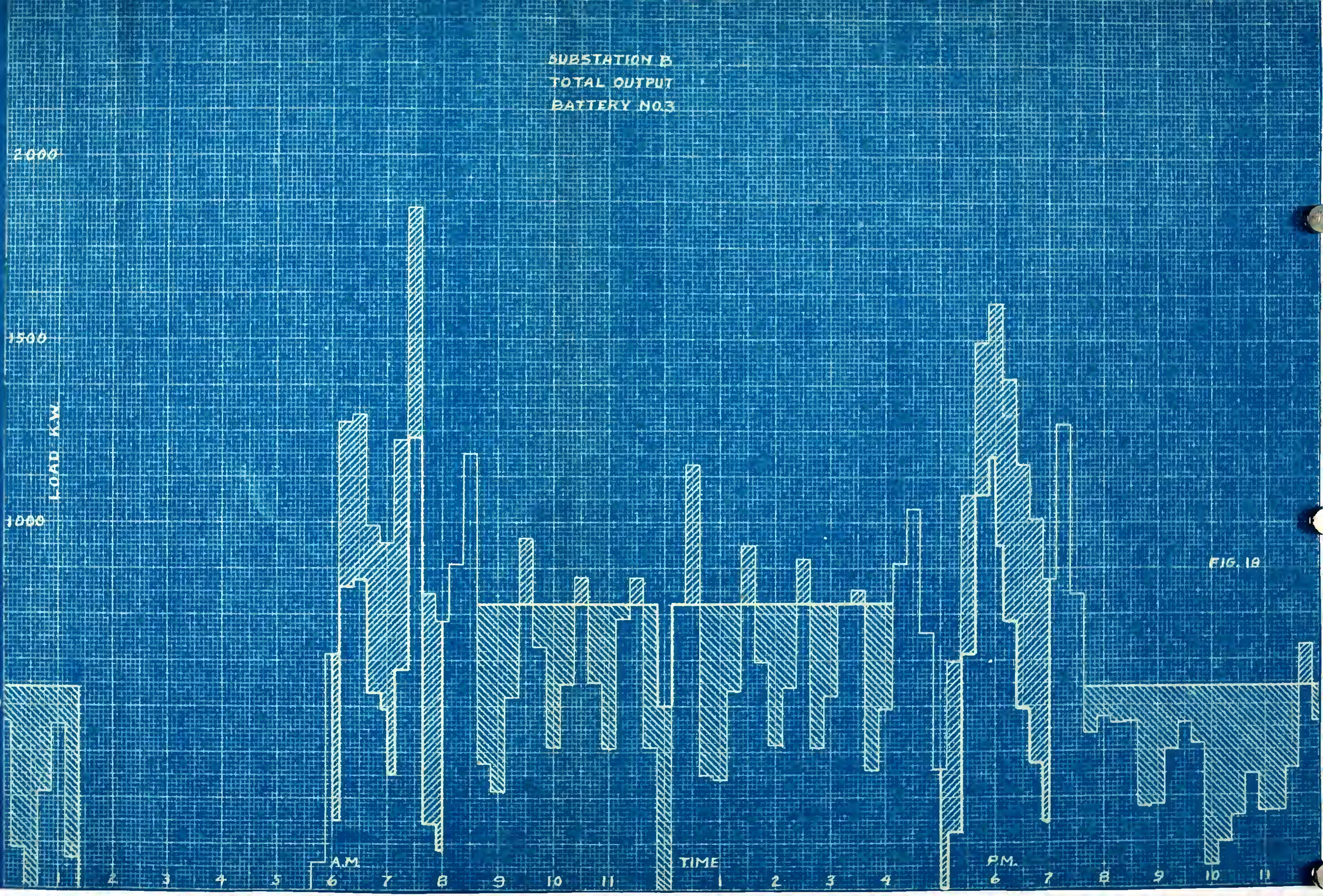


FIG. 18

WIRING DIAGRAM
REGULATING BATTERY

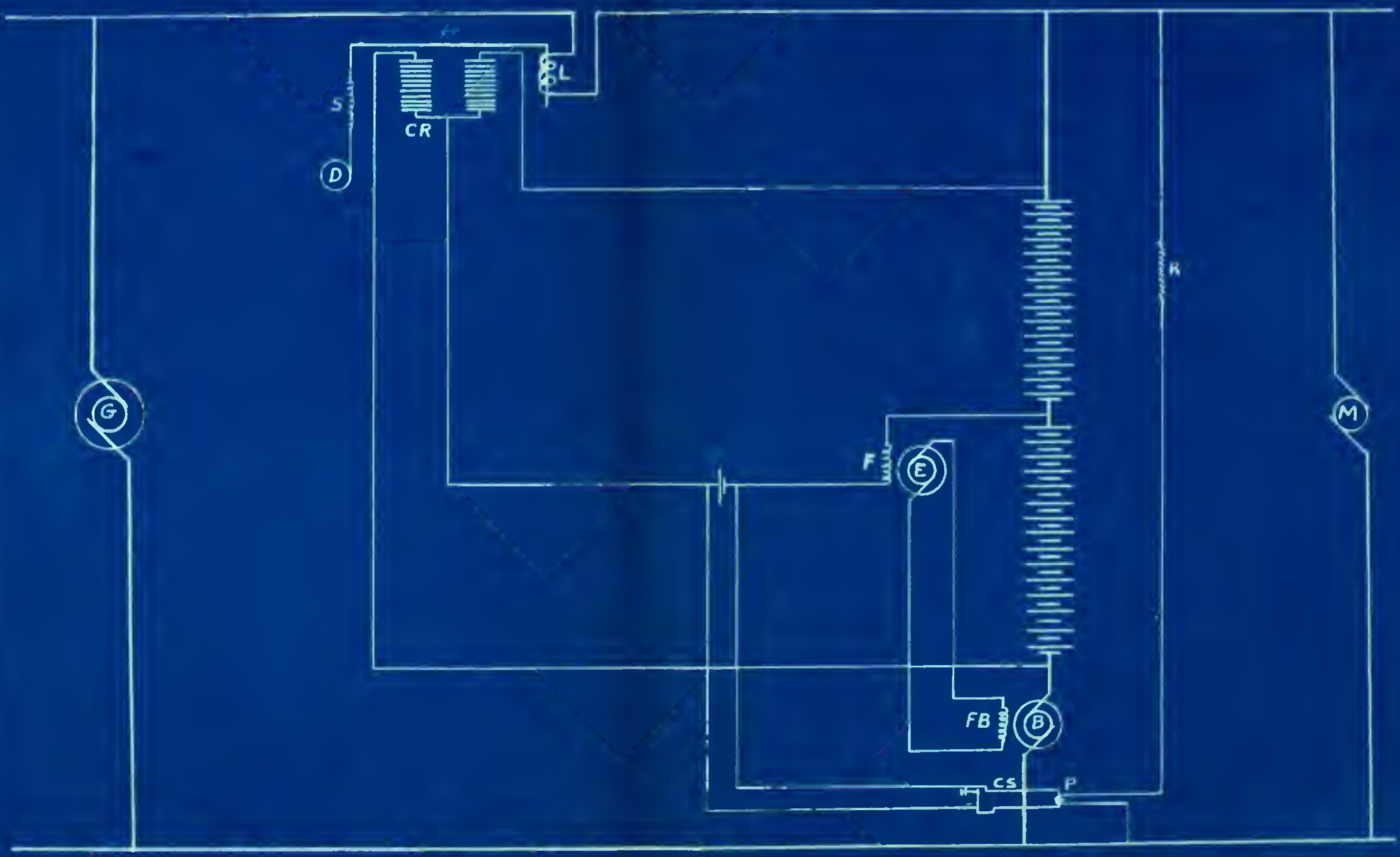


FIG. 20

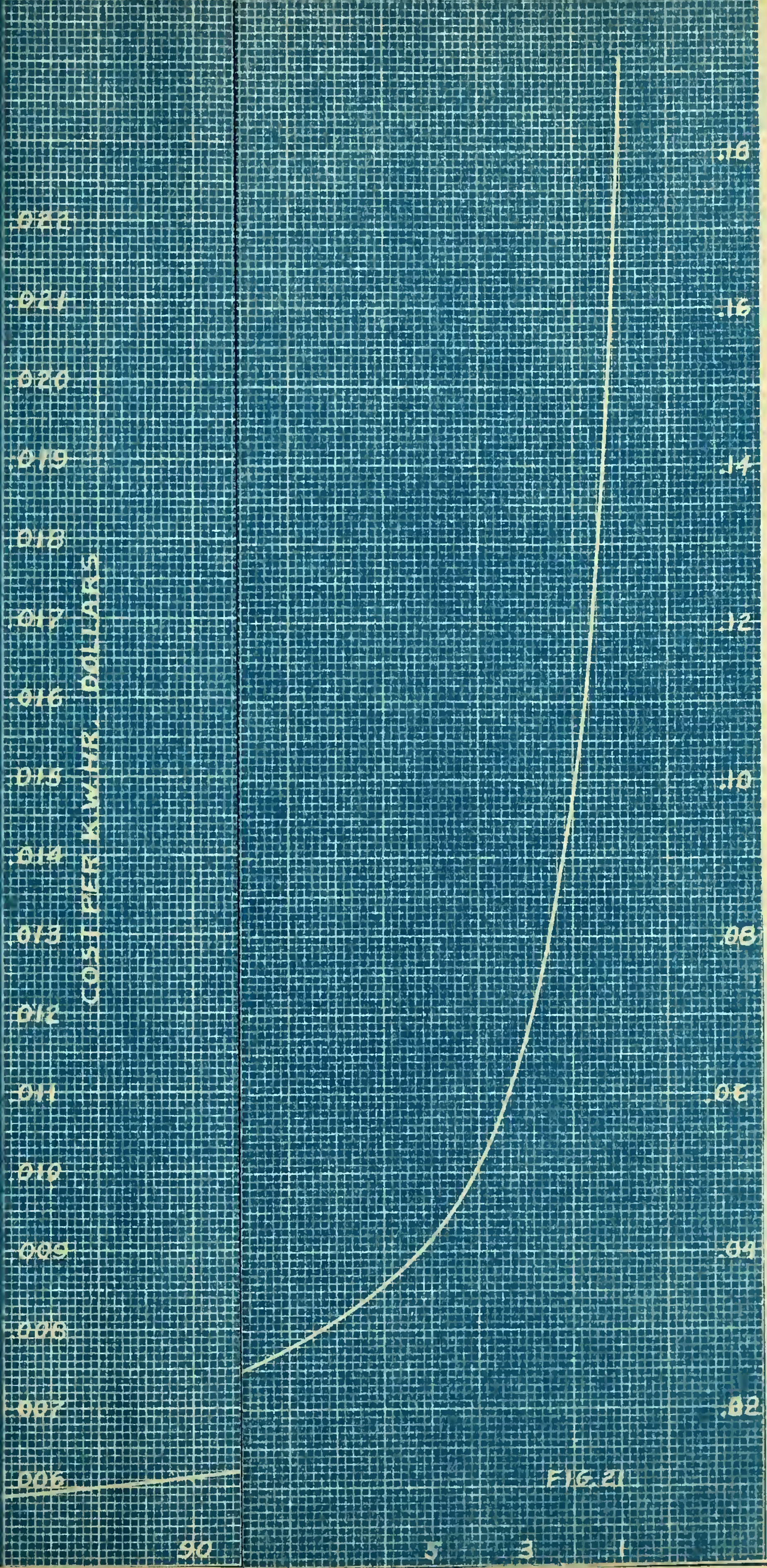

.022
.021
.020
.019
.018
.017
.016
.015
.014
.013
.012
.011
.010
.009
.008
.007
.006
COST PER K.W.HR. DOLLARS
.18
.16
.14
.12
.10
.08
.06
.04
.02
90
5
3
1

FIG. 21

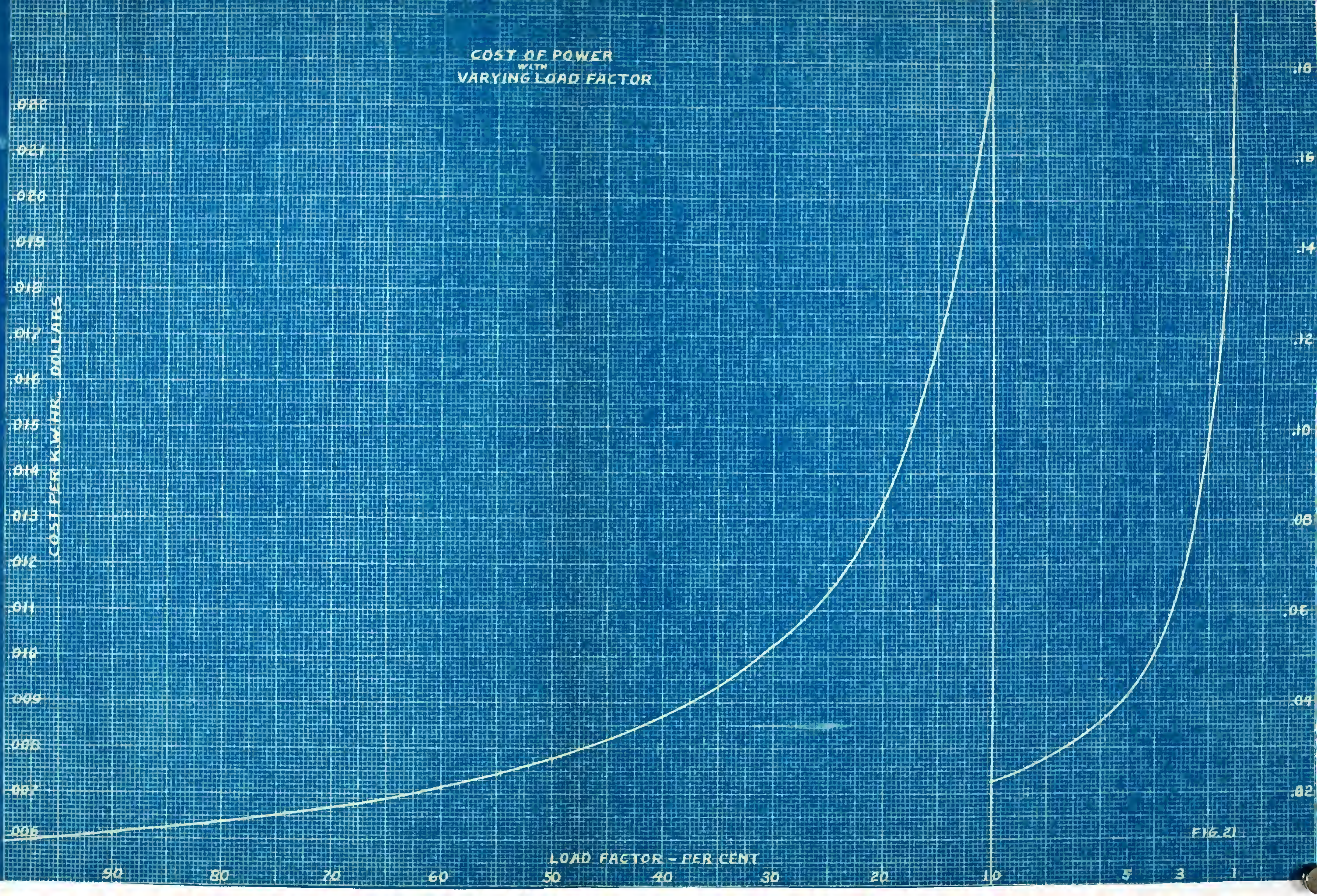

COST OF POWER
WITH
VARYING LOAD FACTOR
COST PER K.W.HR. DOLLARS
.022
.021
.020
.019
.018
.017
.016
.015
.014
.013
.012
.011
.010
.009
.008
.007
.006
.18
.16
.14
.12
.10
.08
.06
.04
.02
LOAD FACTOR - PER CENT
90
80
70
60
50
40
30
20
10
5
3
1

FIG. 21

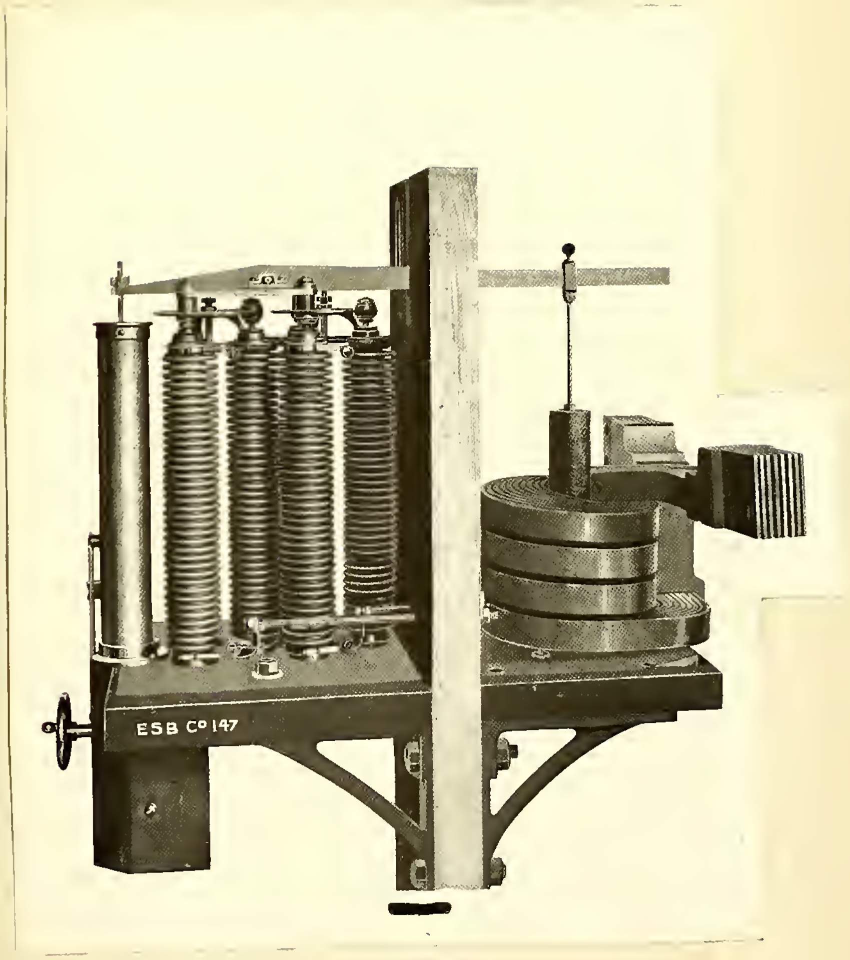


FIGURE 22.

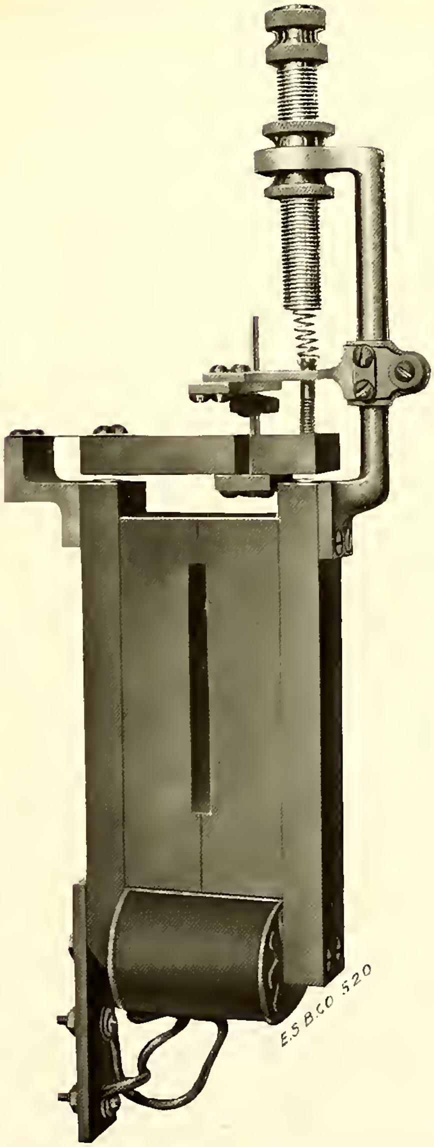


FIGURE 23.